Optoelectronică

Curs 5

2019/2020

Disciplina 2019/2020

- 2C/1L Optoelectronică OPTO
- Minim 7 prezente curs + laborator
- Curs – conf. Radu Damian
  - an IV μE
  - Vineri 8-11, P5
  - E – 70% din nota
    - **20% test la curs**, saptamana 4-5?
  - probleme + (? 1 subiect teorie) + (2p prez. curs)
  - toate materialele permise
- Laborator – sl. Daniel Matasaru
  - an IV μE
    - Joi 8-14 impar
  - L – 30% din nota (+Caiet de laborator)

Fibra optică – Tehnologie

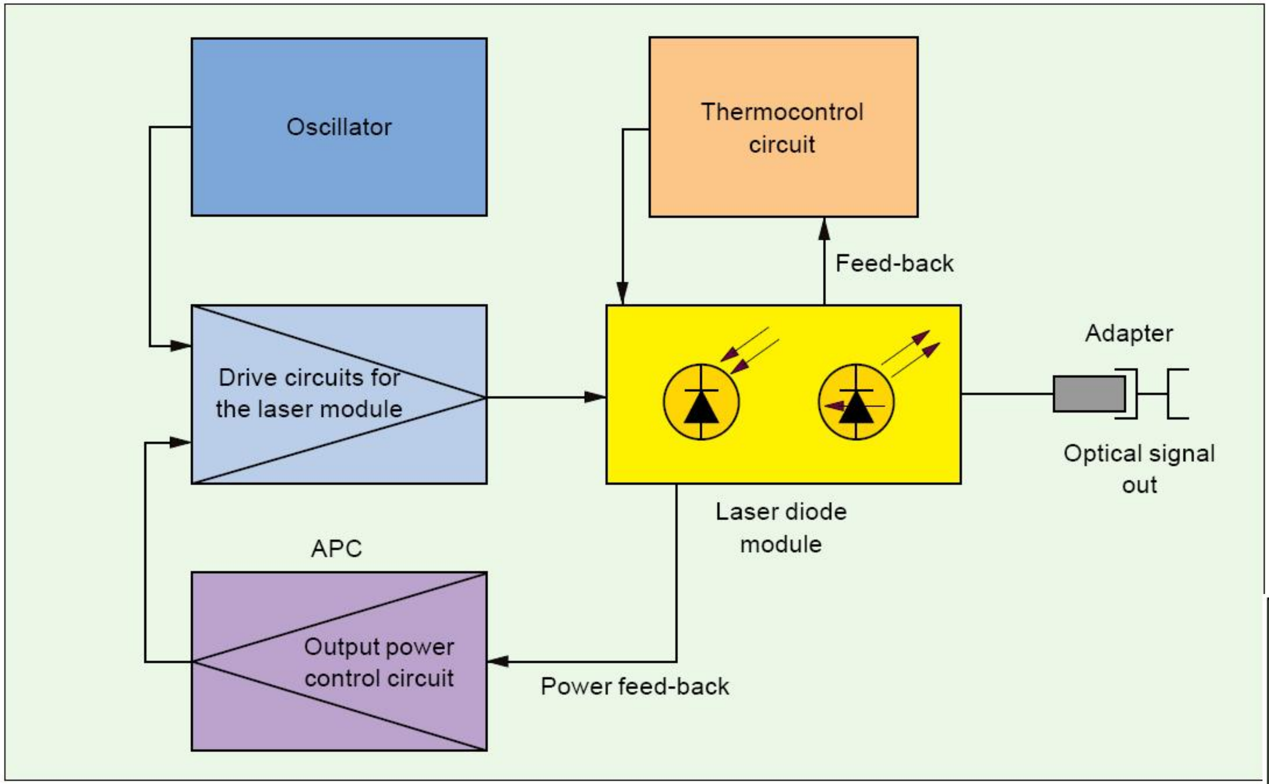
Capitolul 5

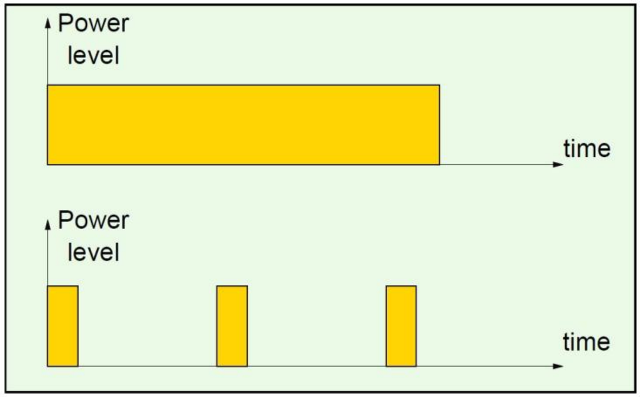
Cuprins

- **Lumina ca undă electromagnetică** (ecuaţiile lui Maxwell, ecuaţia undelor, parametrii de propagare)
- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
- **Fibra optică** (realizare, principiu de funcţionare, atenuare, dispersie, banda de frecvenţă)
- **Cabluri optice** (tehnologie, conectori, lipire - splice)
- **Proiectare sistemică a legăturii pe fibra optică** (bandă de frecvenţă, balanţa puterilor)
- **Emiţătoare optice** (LED şi dioda laser - realizare fizică şi functionare)
- **Receptoare optice** (dioda PIN, dioda cu avalanşă - realizare fizică şi functionare)
- **Amplificatoare transimpedanţă** (parametri, scheme tipice, TIA în buclă deschisă, cu reacţie, diferenţiale, control automat al câştigului)
- **Realizarea circuitelor pentru controlul emiţătoarelor optice (**parametri, scheme tipice, controlul puterii, multiplexoare**)**
- **Dispozitive de captare a energiei solare** (principiu de functionare, utilizare, proiectare)

Stabilized light source Optical power meter

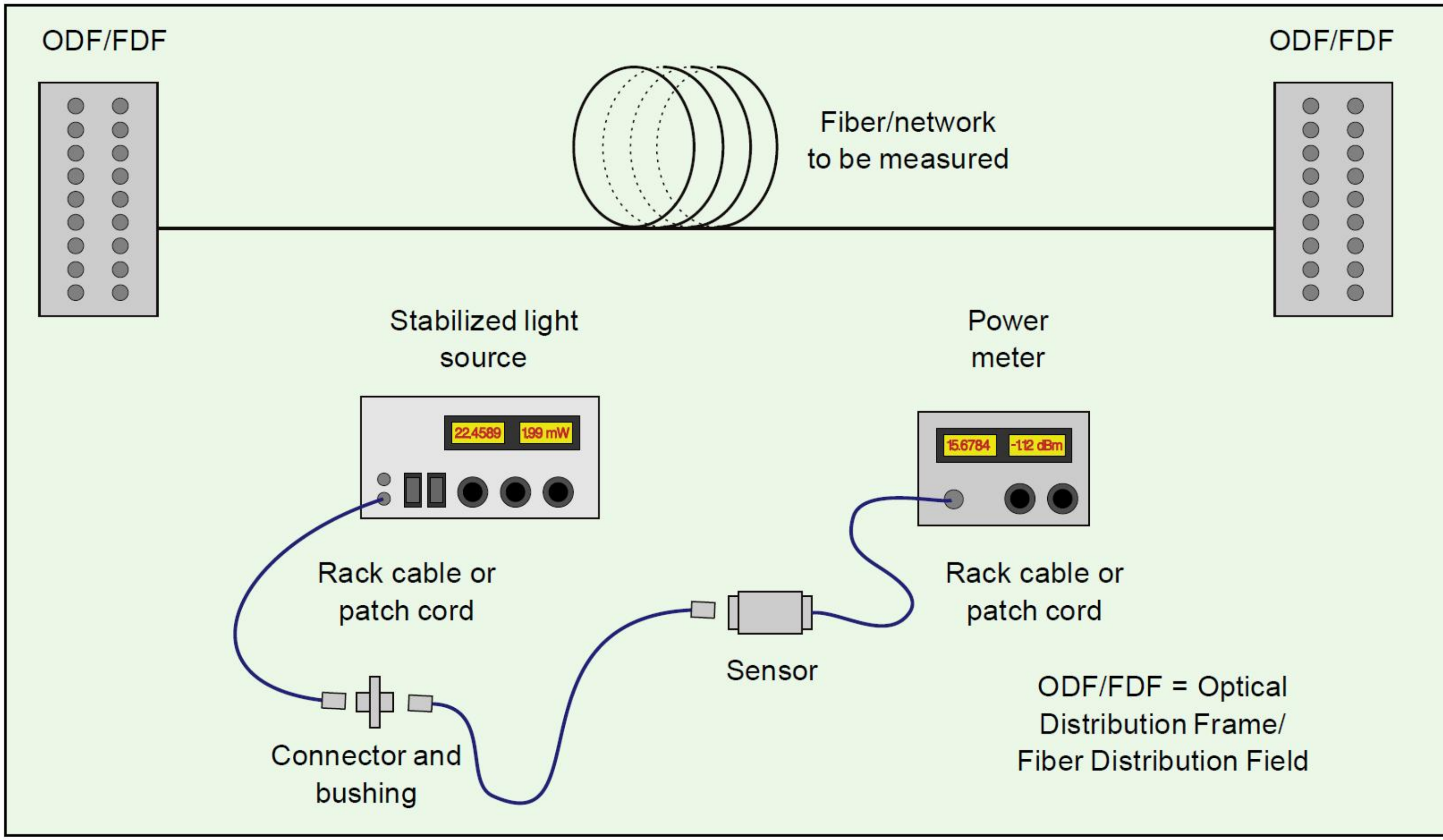
- Masurarea puterii si atenuarii





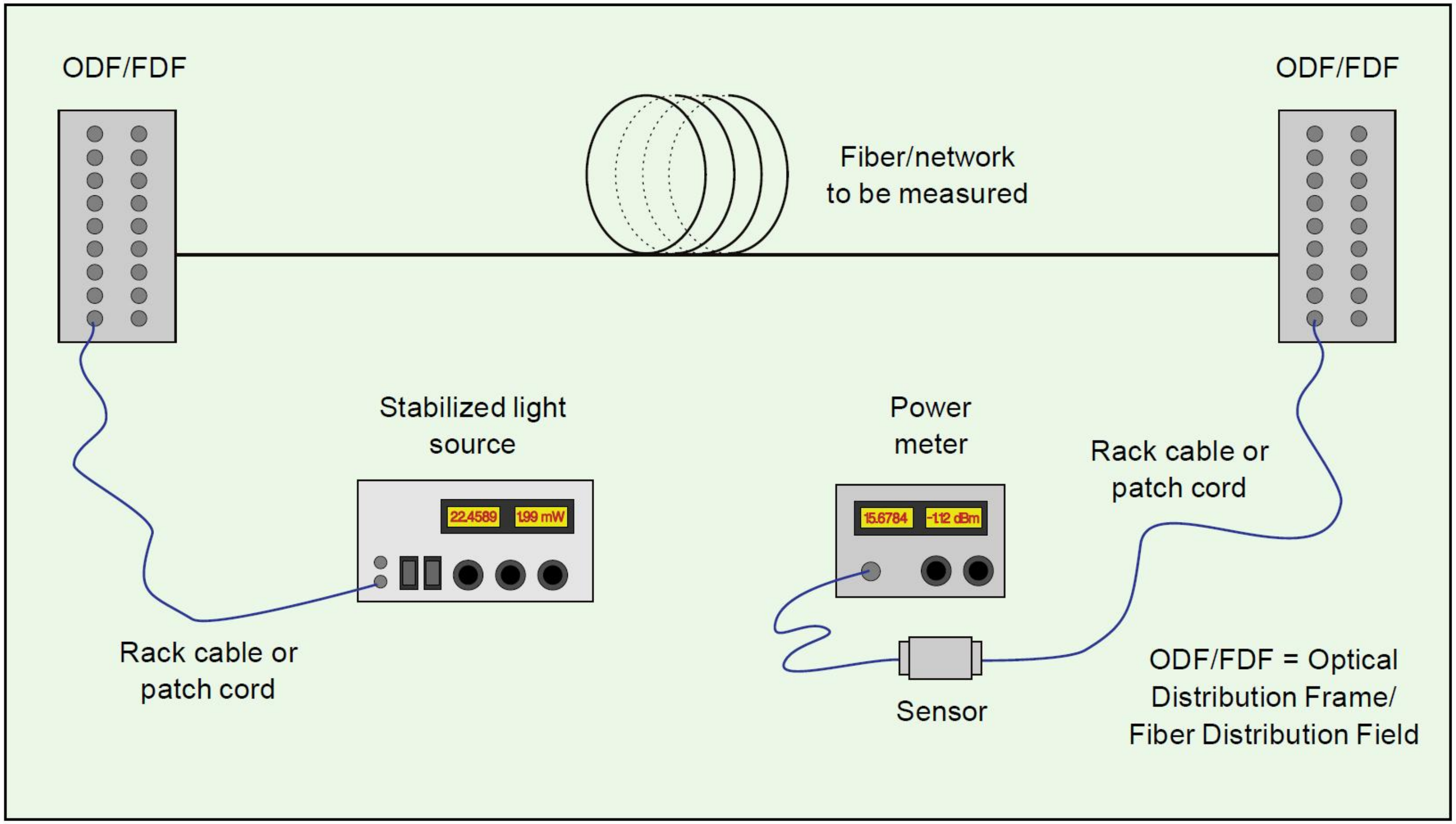
Masurarea puterii si atenuarii

- Masuratoare referinta



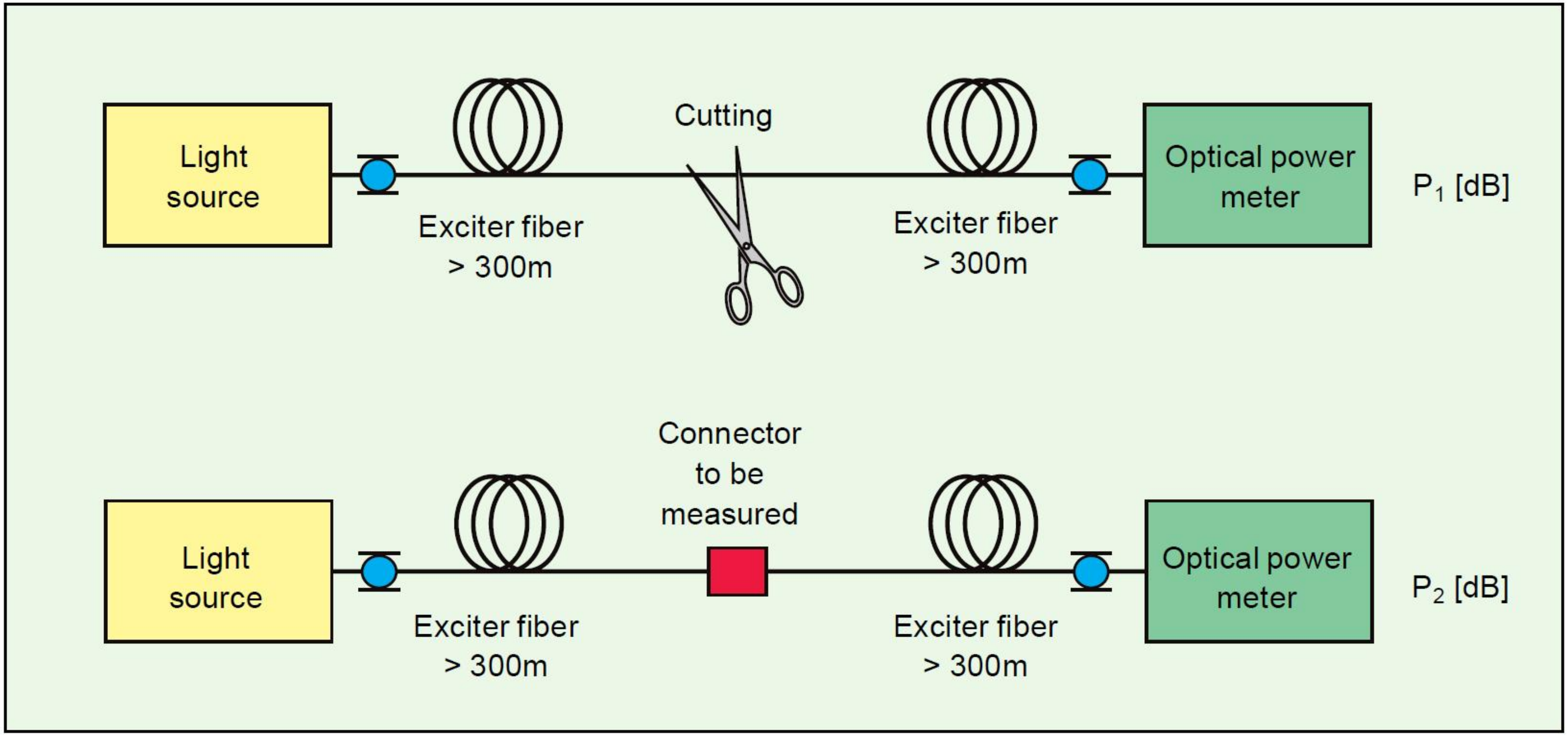
Masurarea puterii si atenuarii

- Masuratoare instalatie



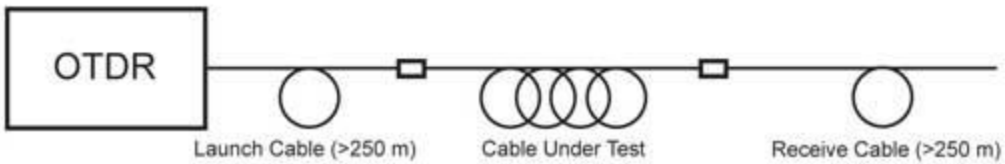
Masurare conectori si splice

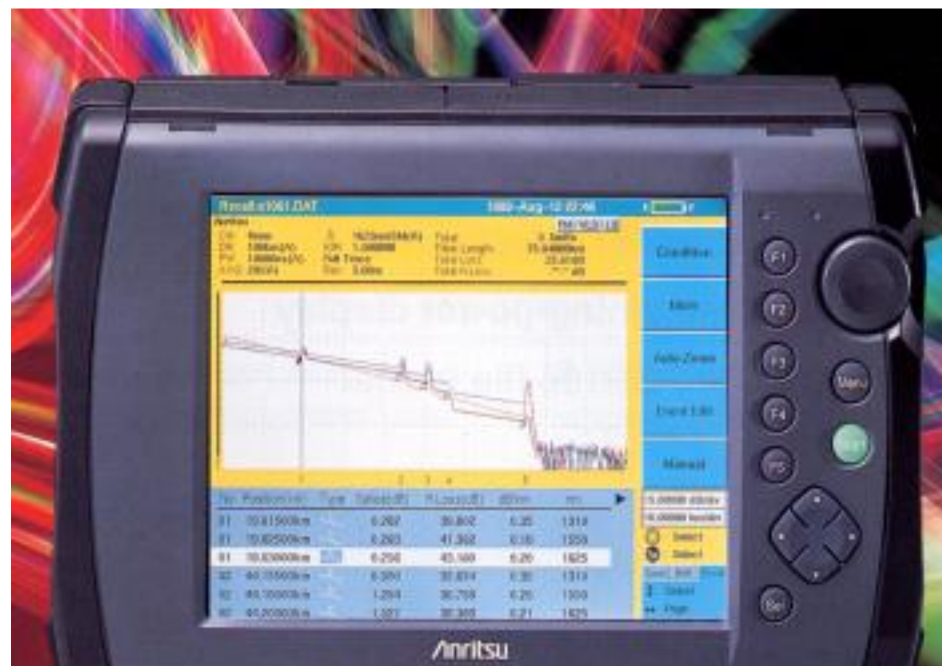
- Se elimina efectele fibrei



OTDR

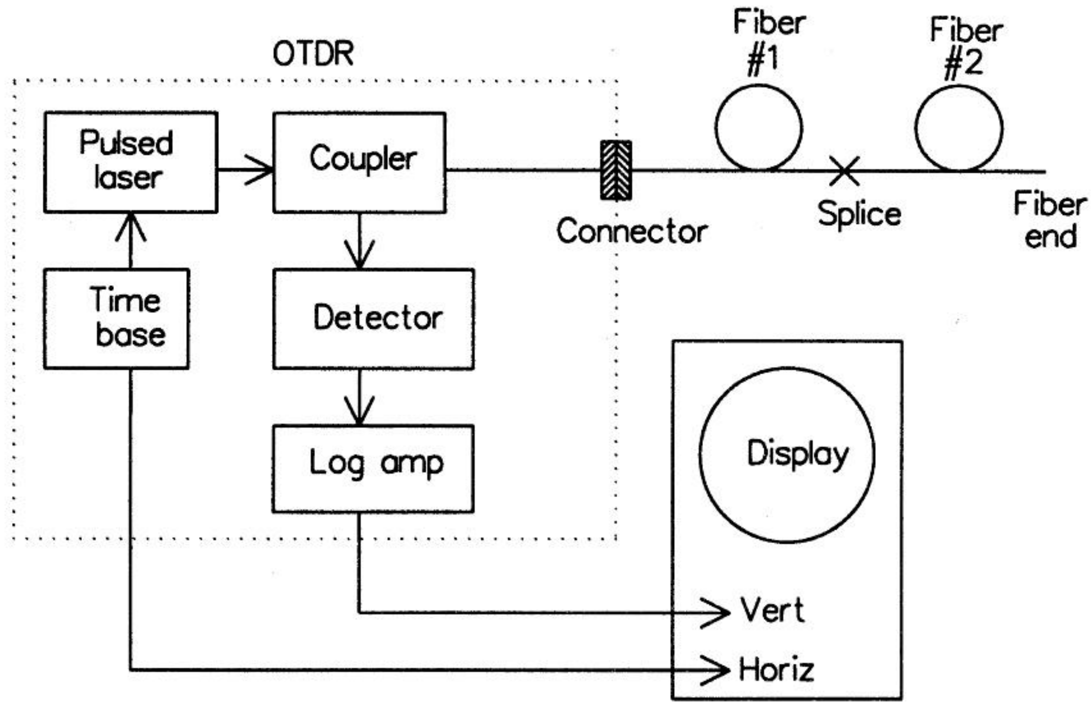
- Optical Time-Domain Reflectometer
- Localizarea defectelor



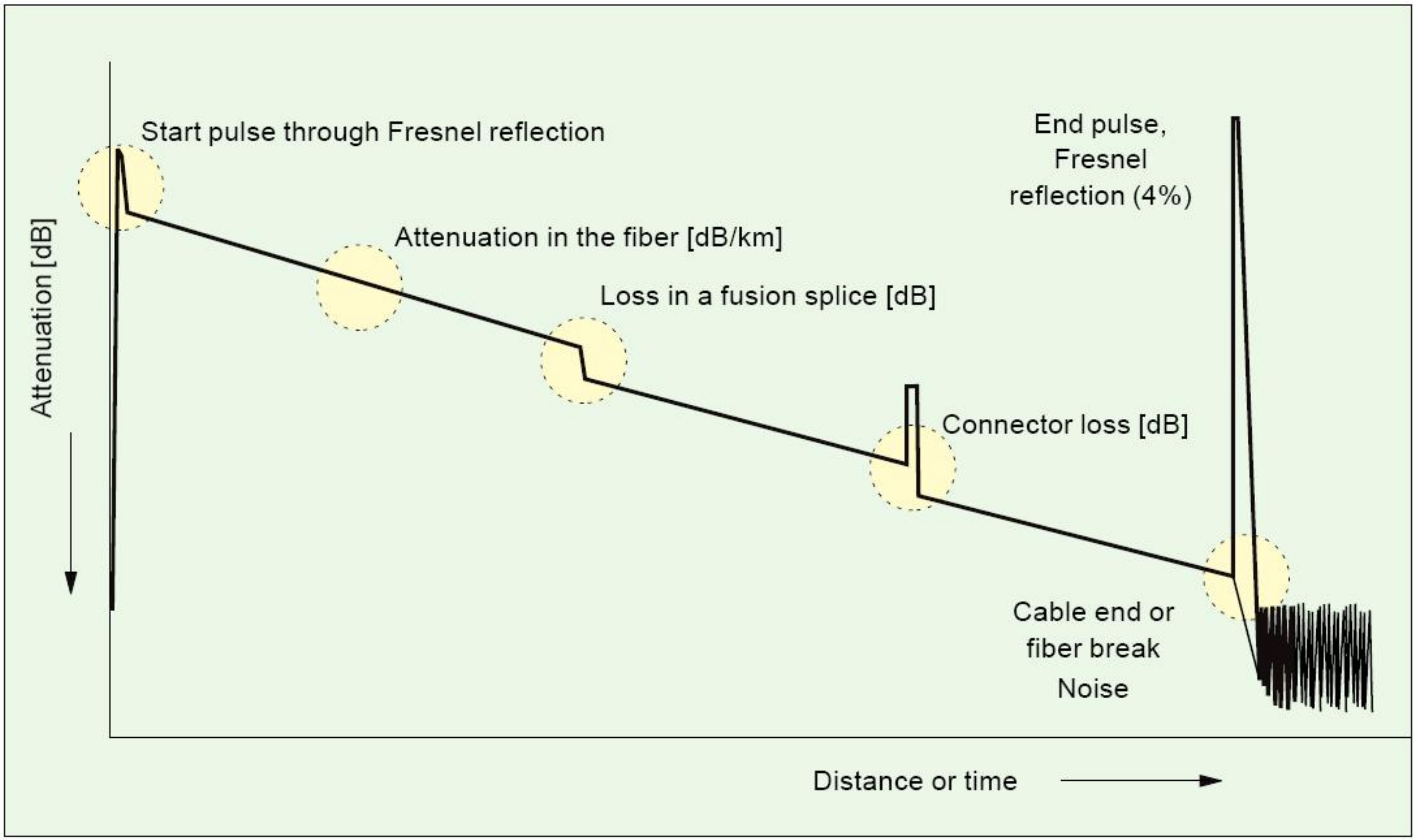


OTDR

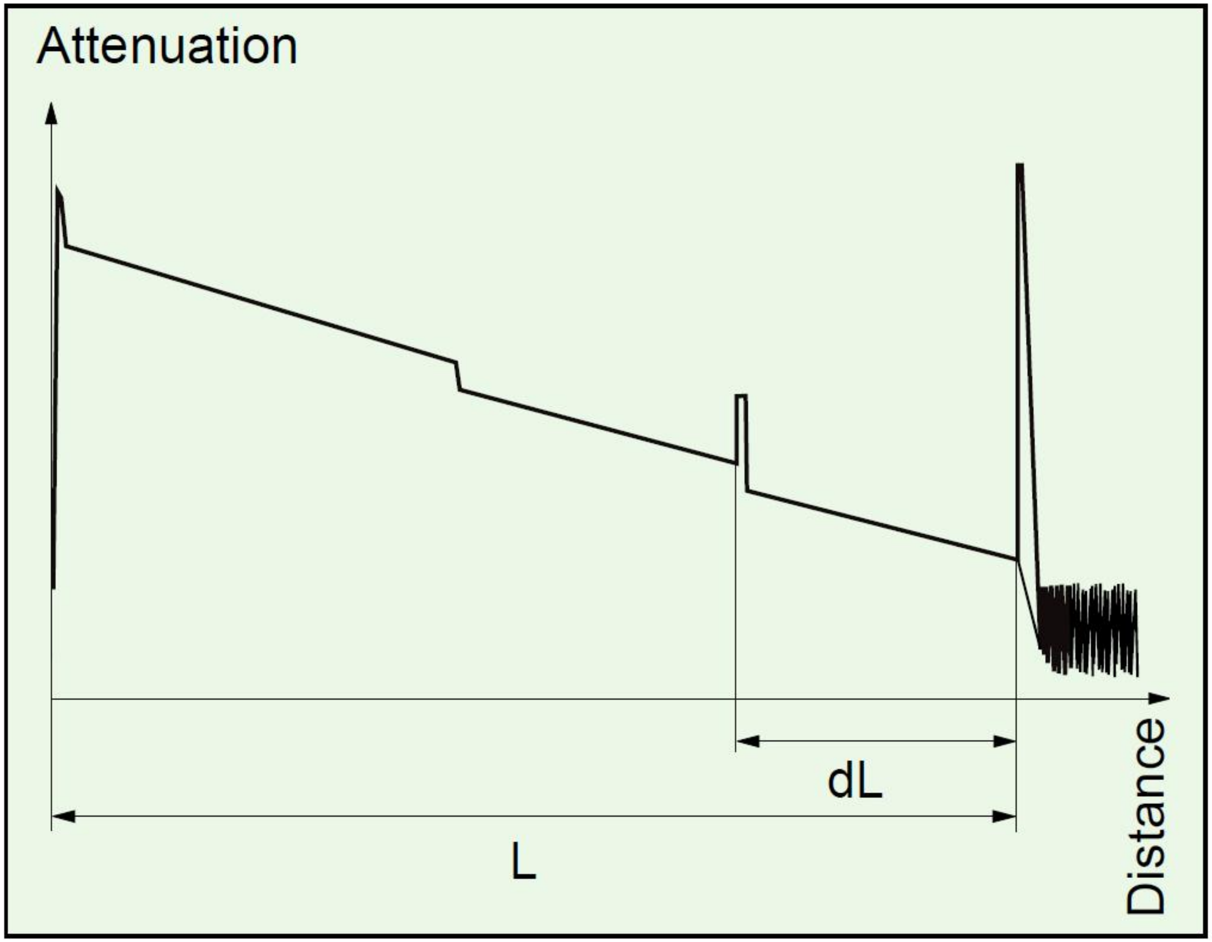
- Optical time-domain reflectometer
- Localizarea defectelor



Rezultat grafic al OTDR



Efecte vizibile OTDR



$$2 \cdot L = c \cdot t$$

$$L = \frac{c_0}{n} \cdot \frac{t}{2}$$

Efecte vizibile OTDR

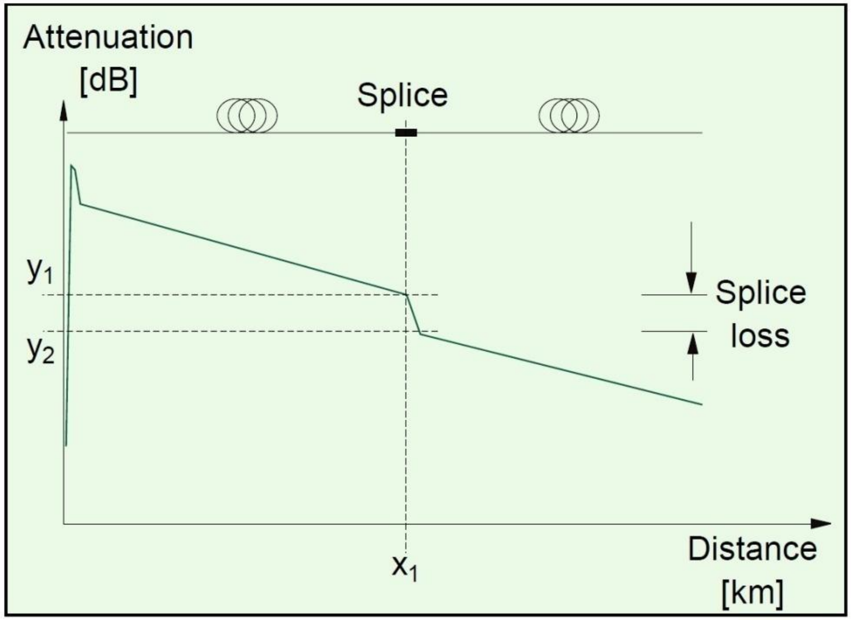
$$A[dB] = \frac{P_1 - P_2}{2}$$

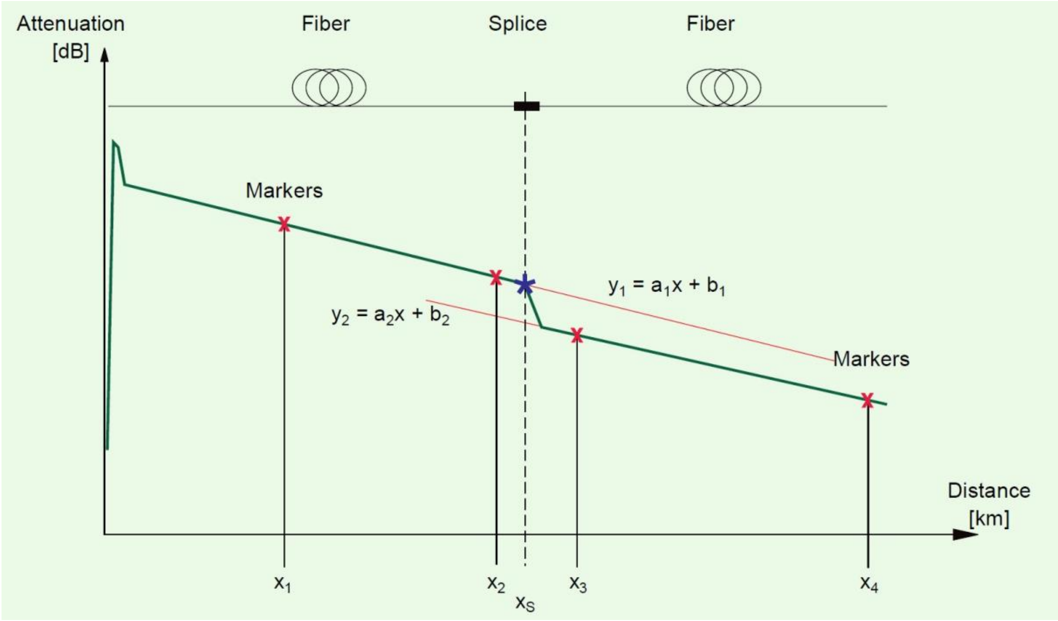
$$A[dB/km] = \frac{P_1 - P_2}{2 \cdot L}$$

panta curbei

Efecte vizibile OTDR – Splice

- splice loss – A(s)

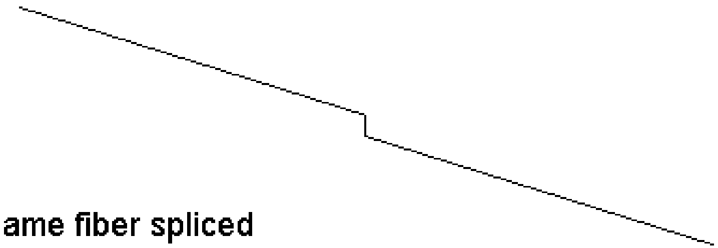




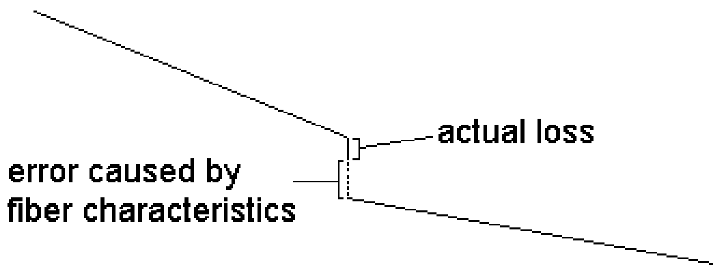
$$A(s) = y_1 - y_2$$

$$A(s) = y_1 - y_2 = x_s \cdot (a_1 - a_2) + (b_1 - b_2)$$

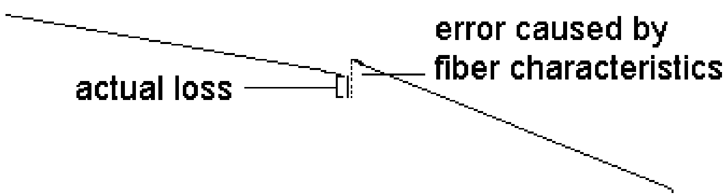
Efecte vizibile OTDR – Splice



a. same fiber spliced



b. high loss fiber spliced to low loss fiber

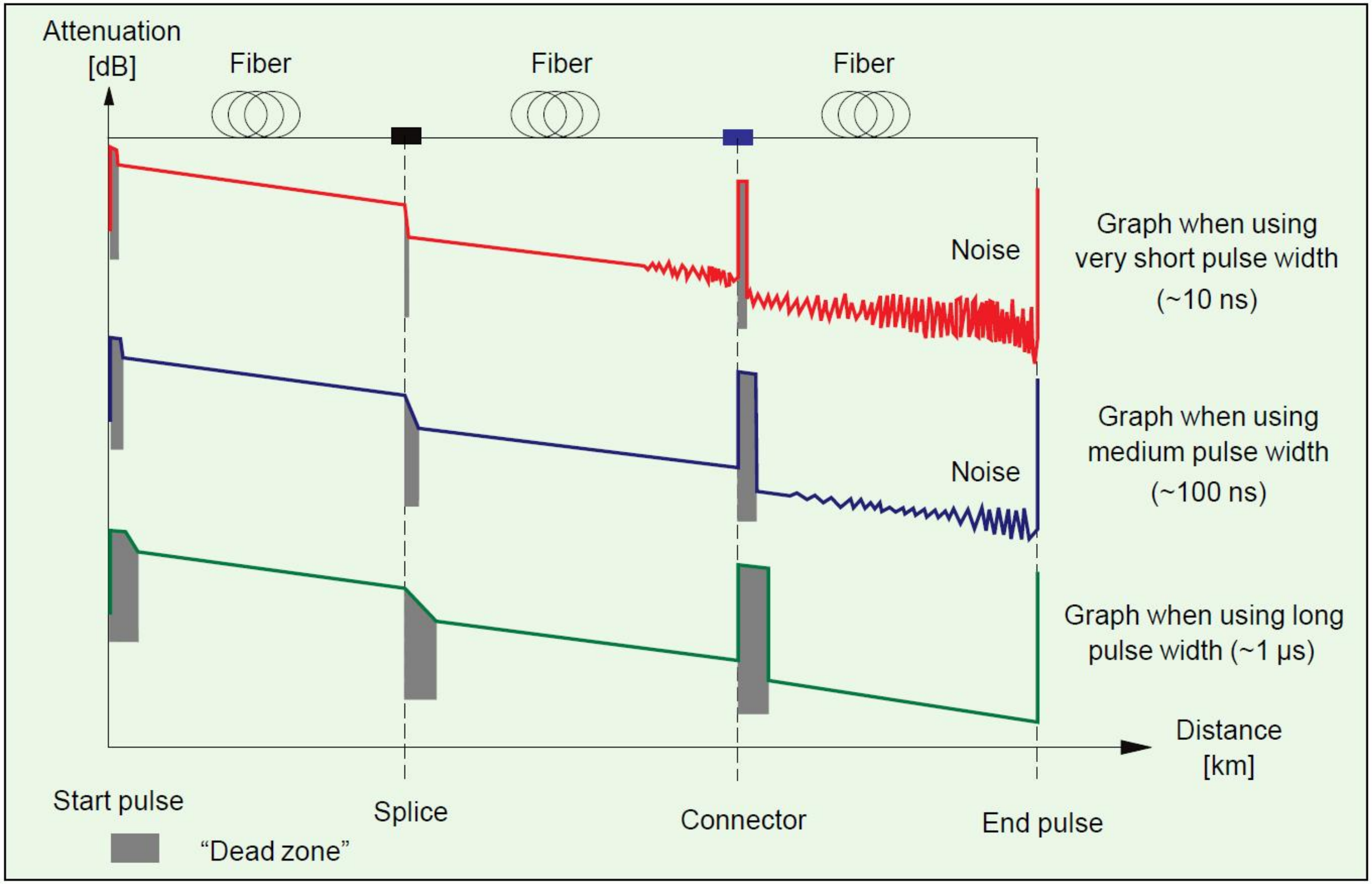


c. low loss fiber spliced to high loss fiber
can cause an apparent gain at a splice

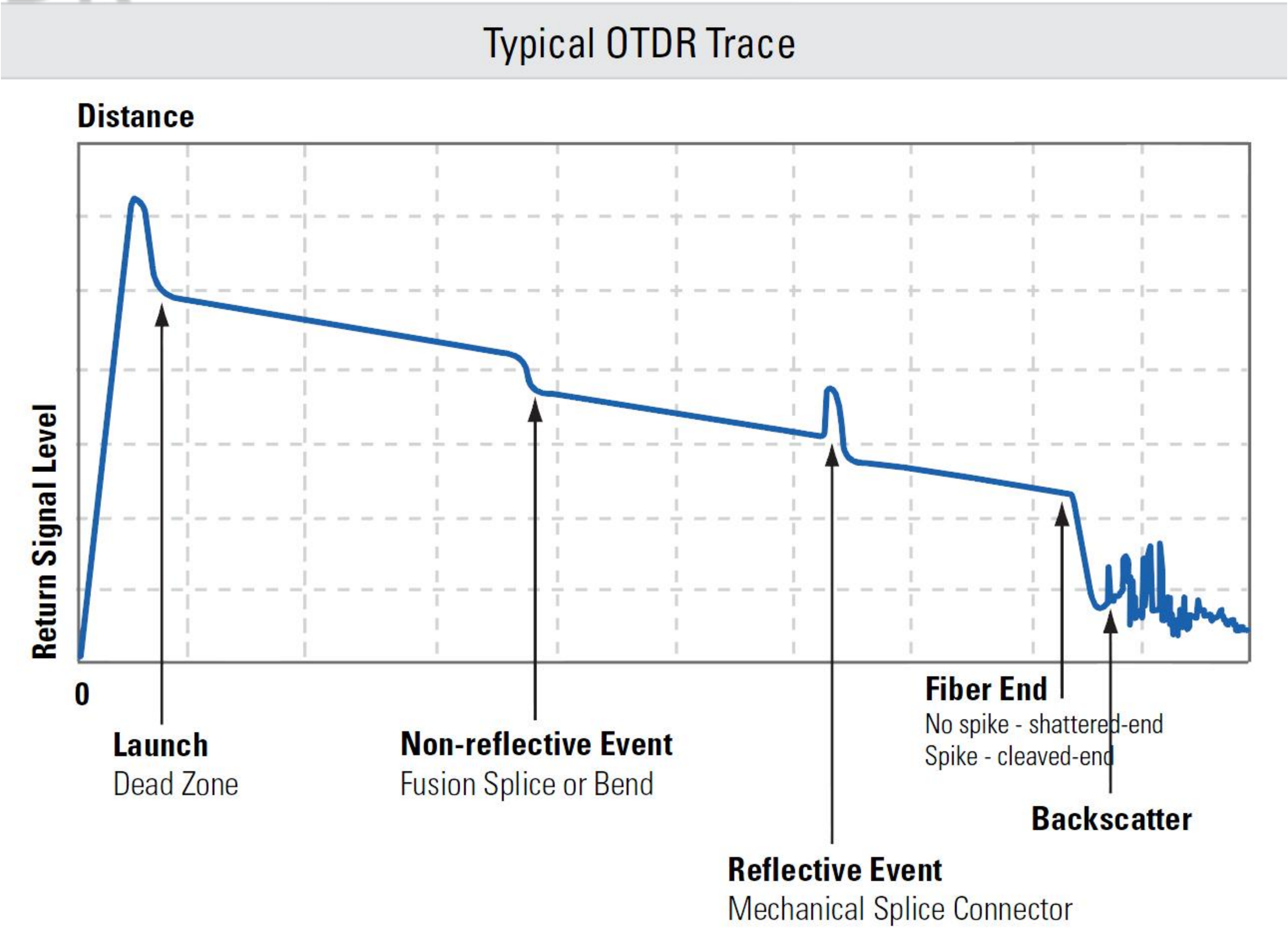
$$A(s) = \frac{A(s)_{A \to B} + A(s)_{B \to A}}{2}$$

Rezultat grafic al OTDR

- latimea pulsurilor luminoase

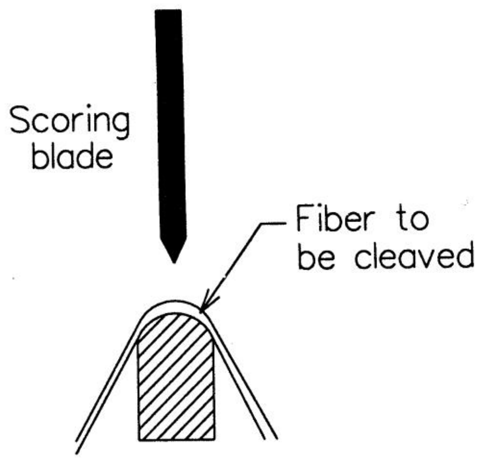


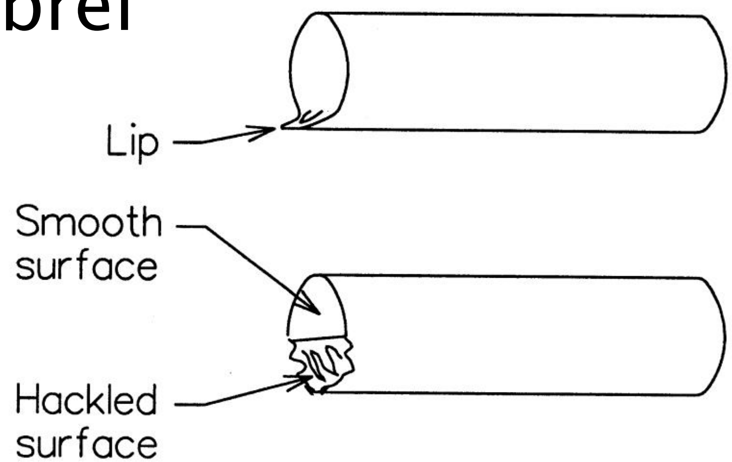
OTDR


Typical OTDR Trace
Distance
Return Signal Level
0
Launch
Dead Zone
Non-reflective Event
Fusion Splice or Bend
Reflective Event
Mechanical Splice Connector
Fiber End
No spike - shattered-end
Spike - cleaved-end
Backscatter

Taiere – Cleaving

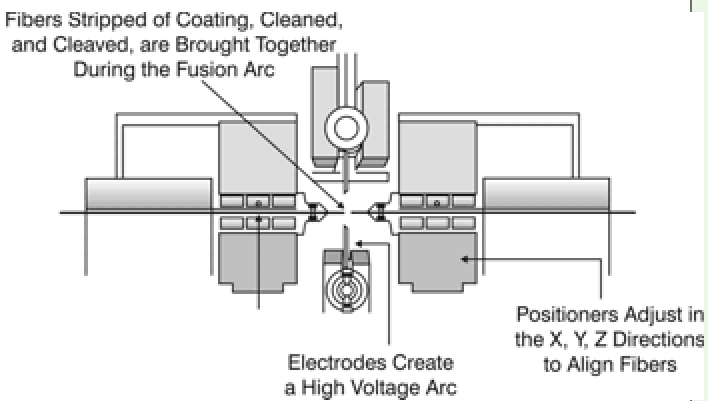
- Tehnici necesare pentru a asigura o taiere perpendiculara pe axa fibrei

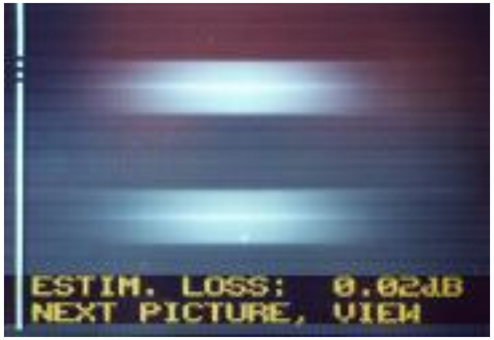


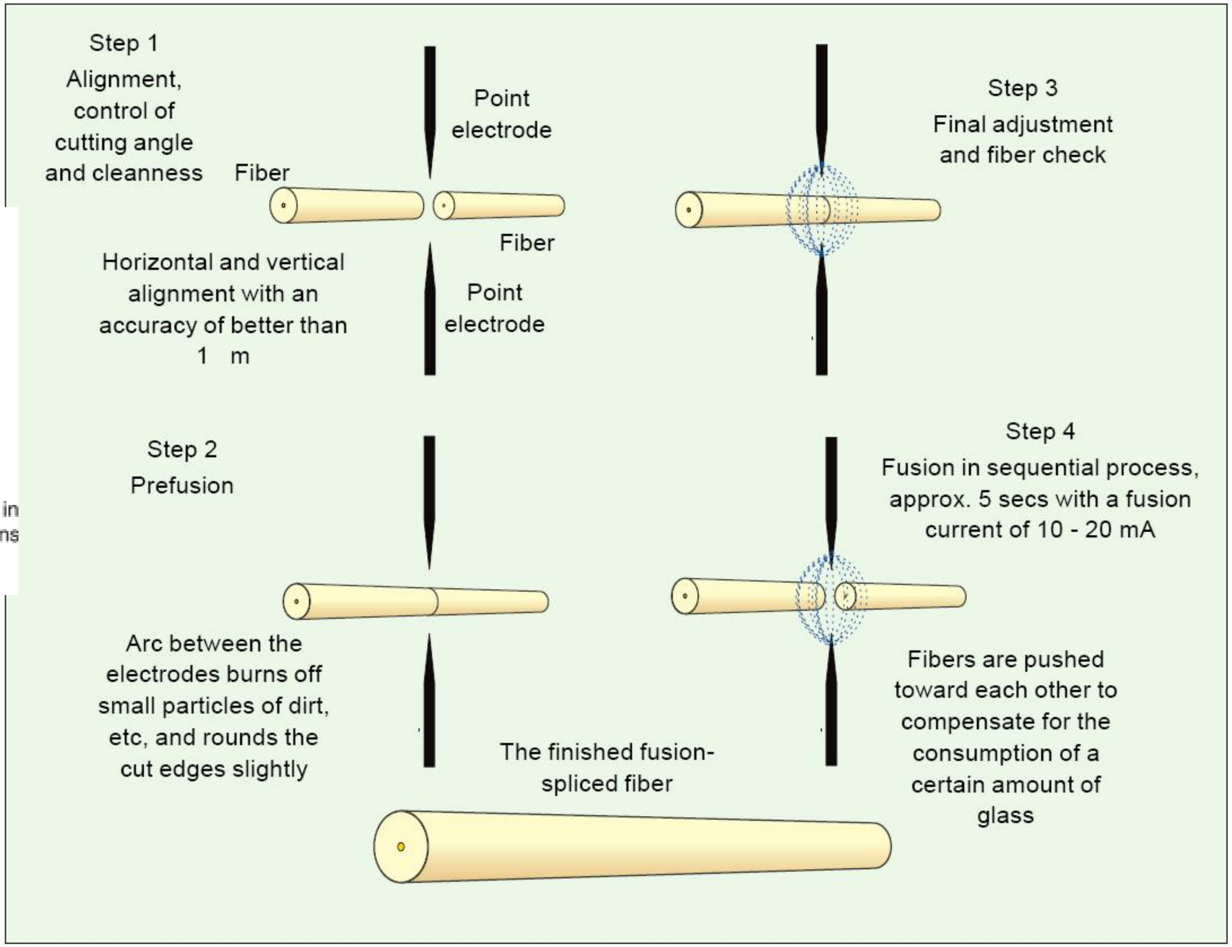


Lipire prin fuziune

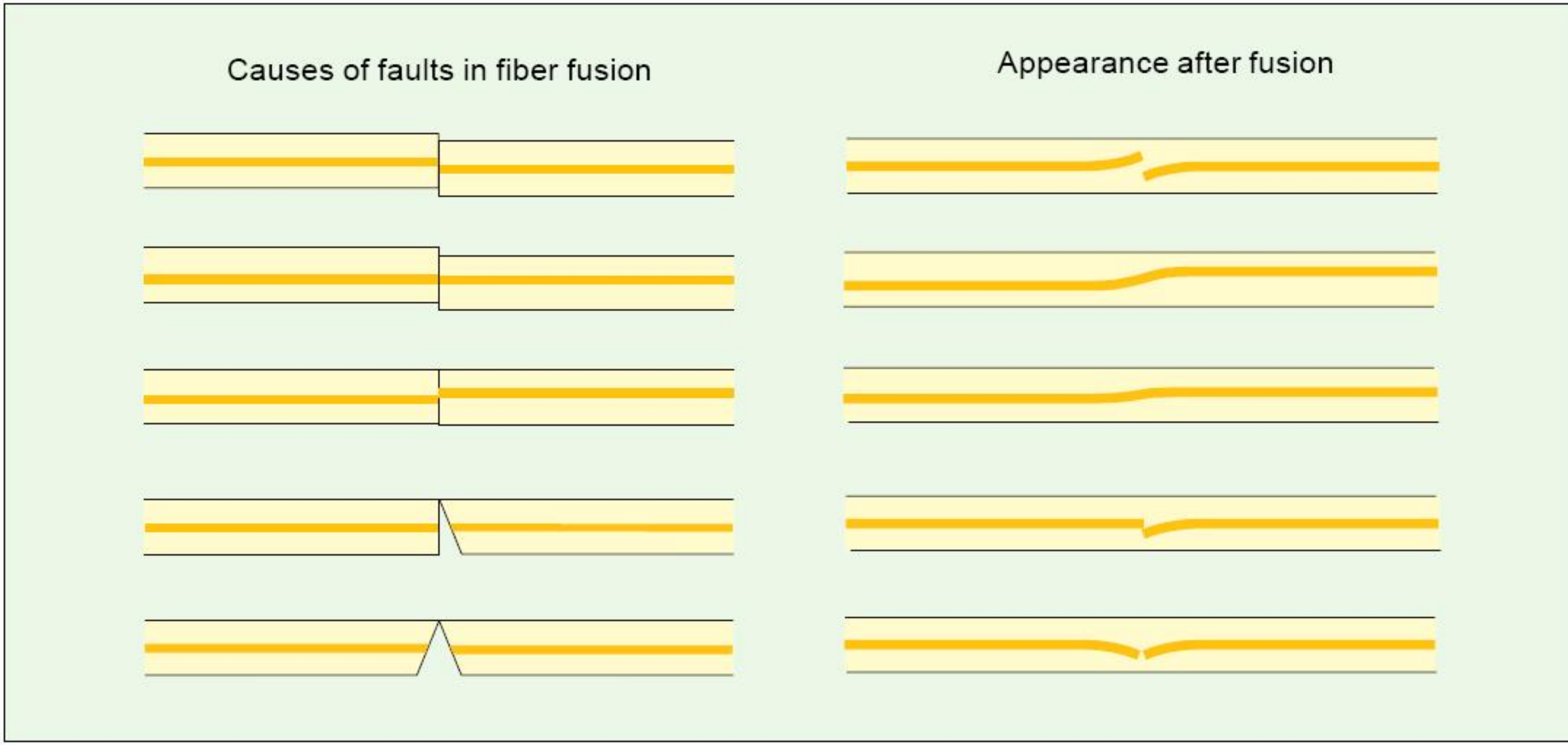
Splice prin fuziune



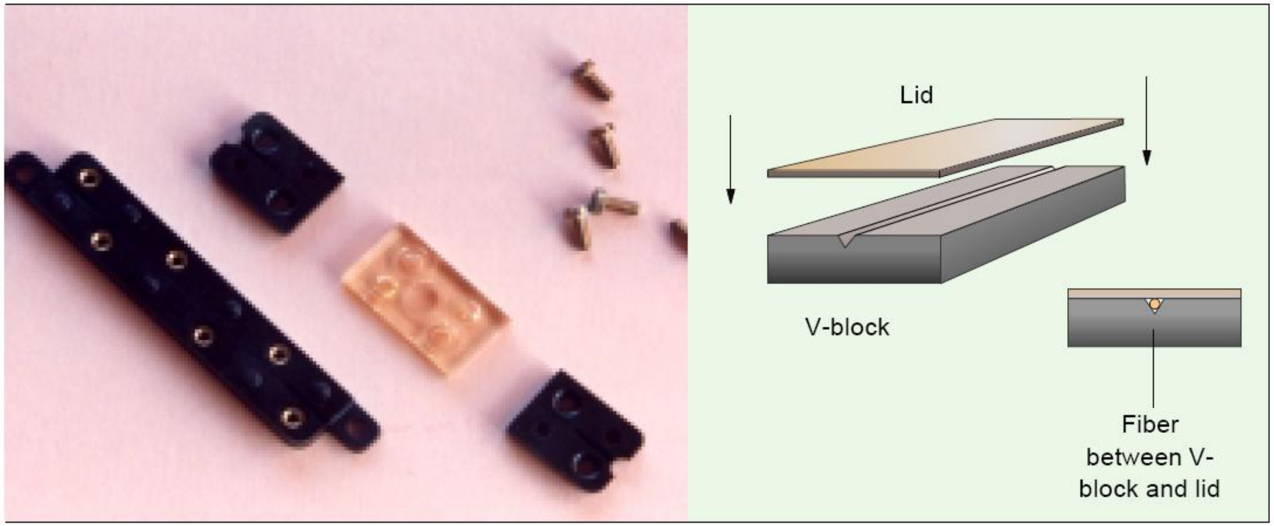


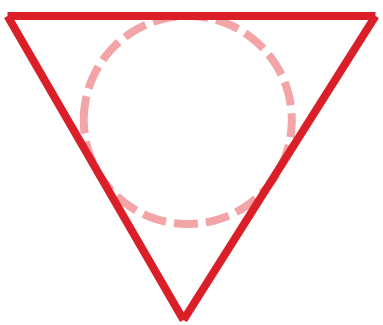


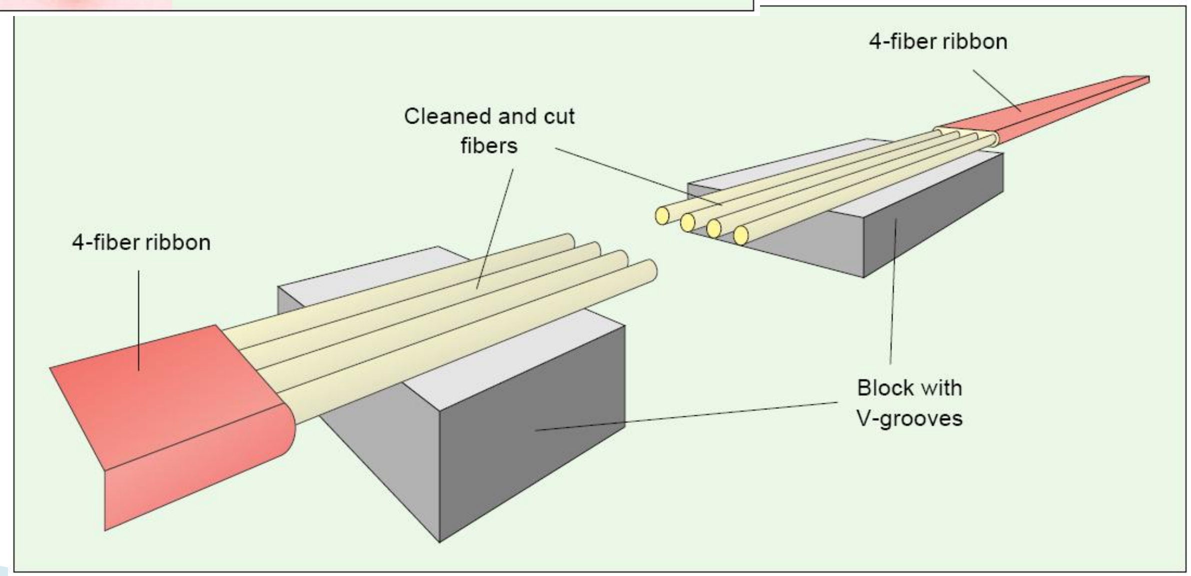
Splice prin fuziune



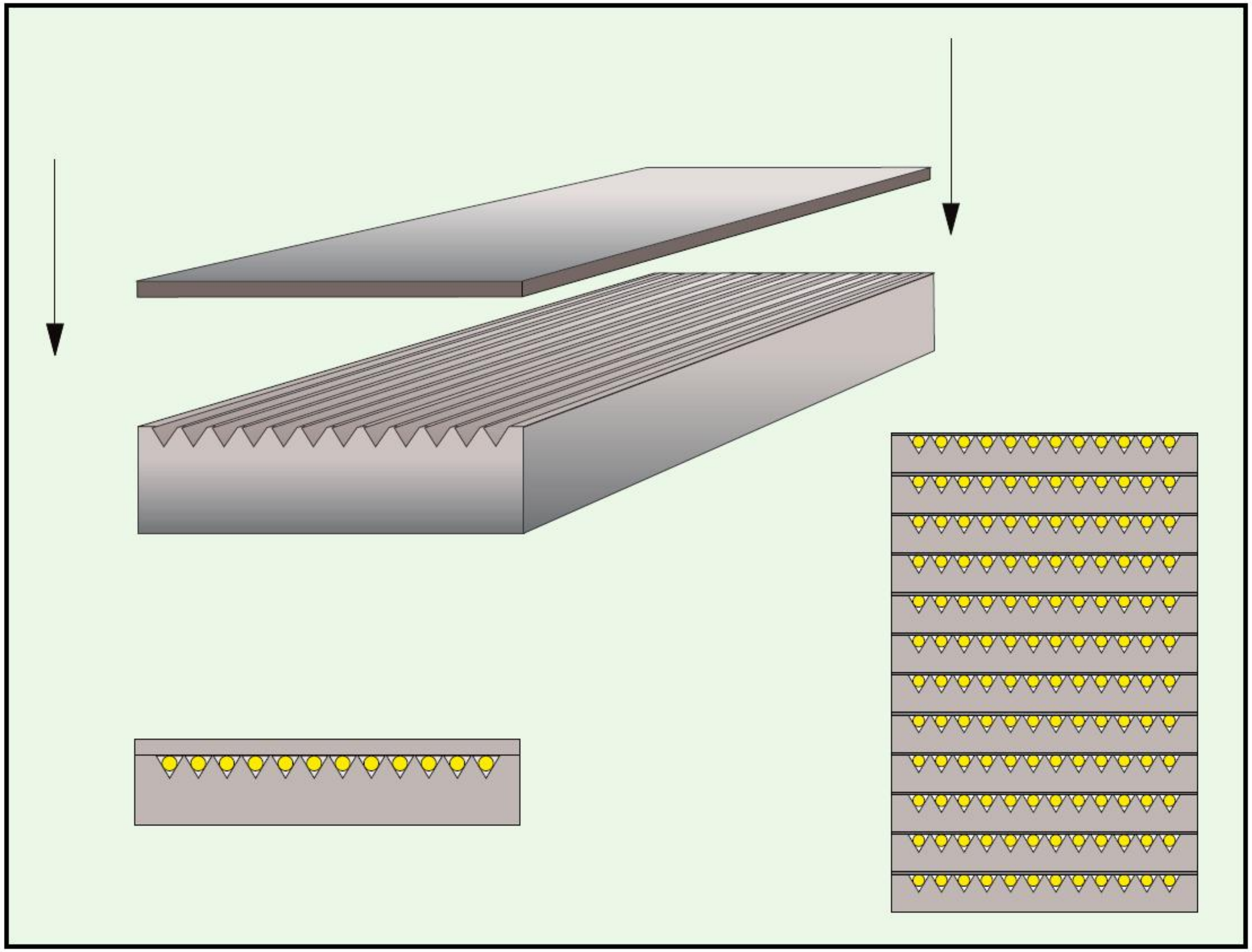
Splice mecanic – bloc V



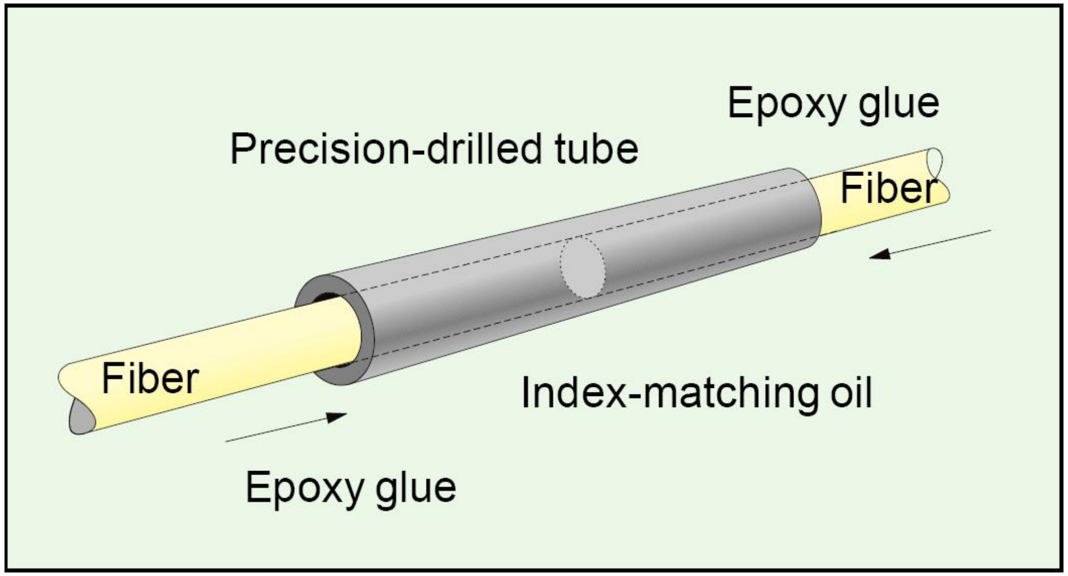


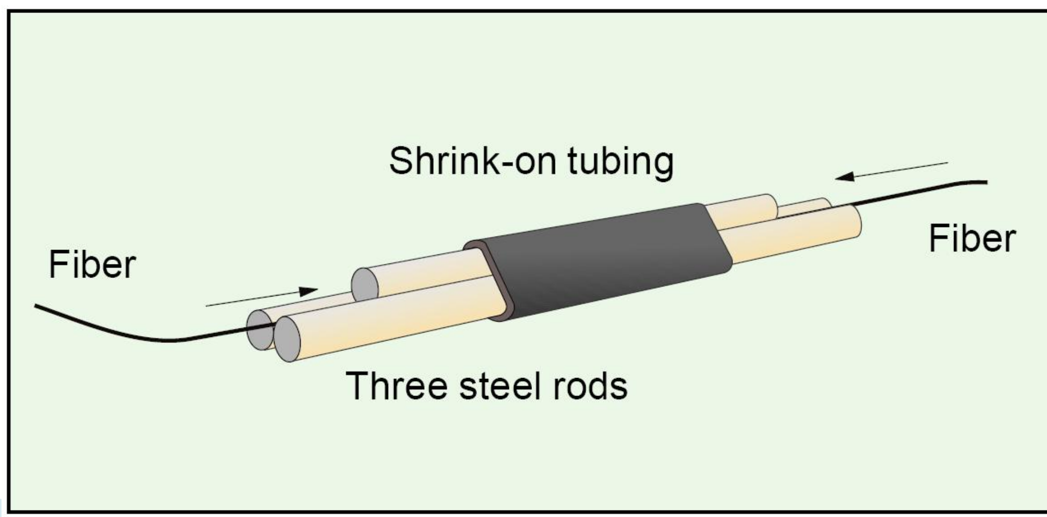


Splice mecanic – bloc V



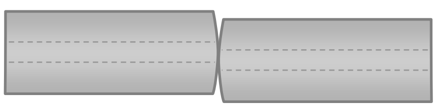
Splice mecanic



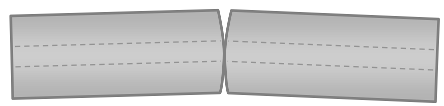


Probleme Fibre/Conectori

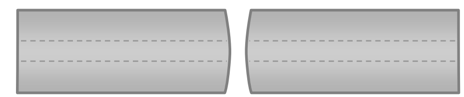
Offset



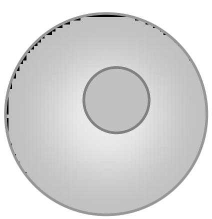
Angular Misalignment



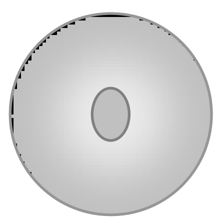
Separation



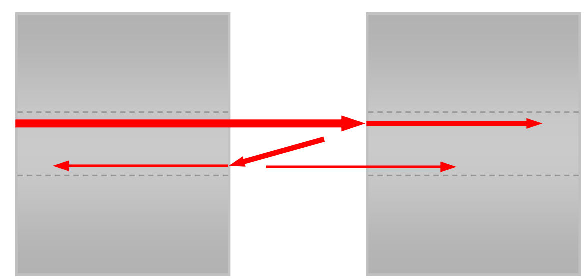
Core Eccentricity



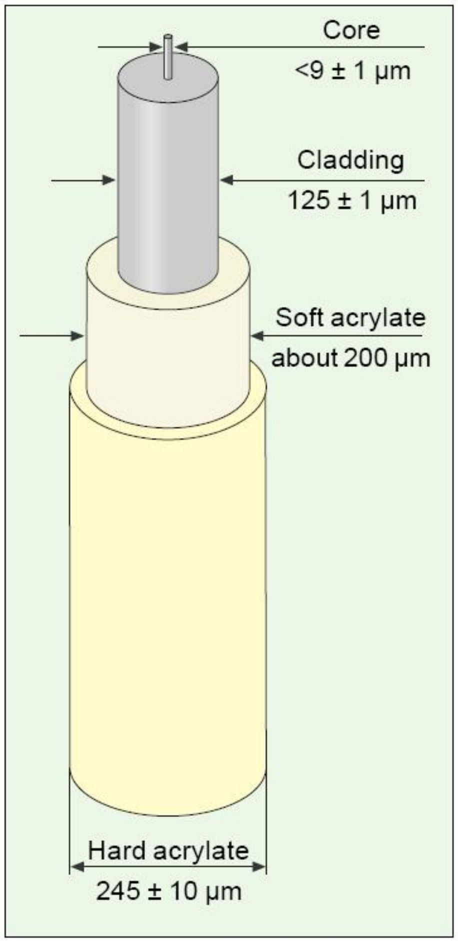
Core Ellipticity

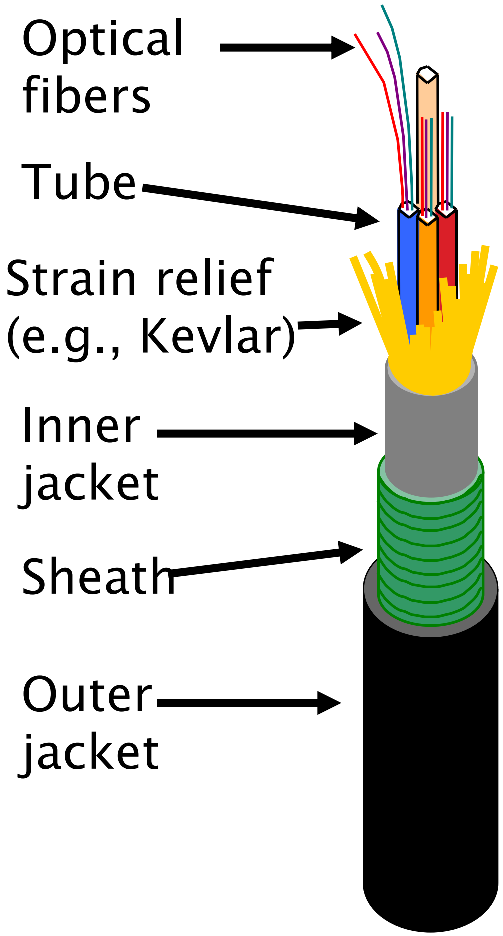


Reflections & Interference

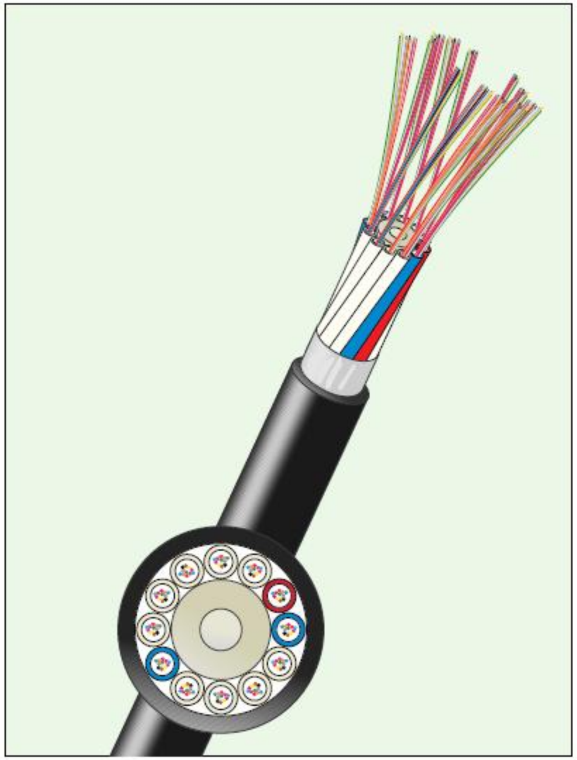


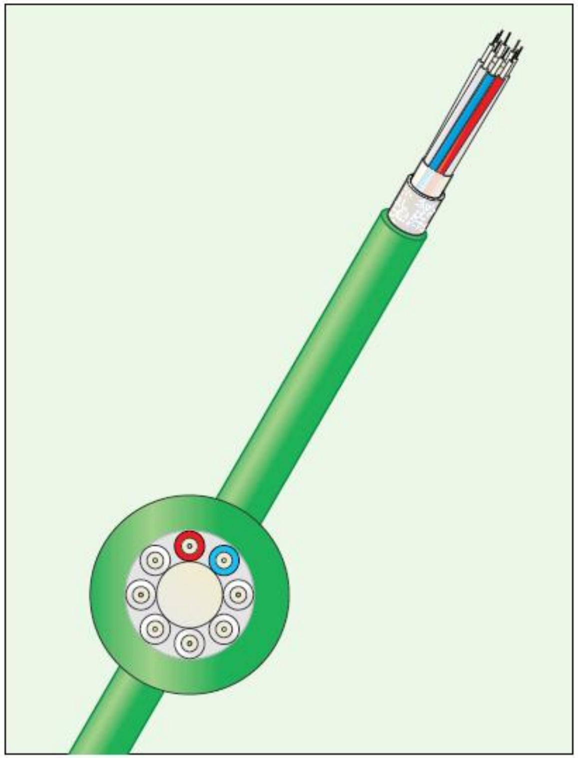
Cabluri

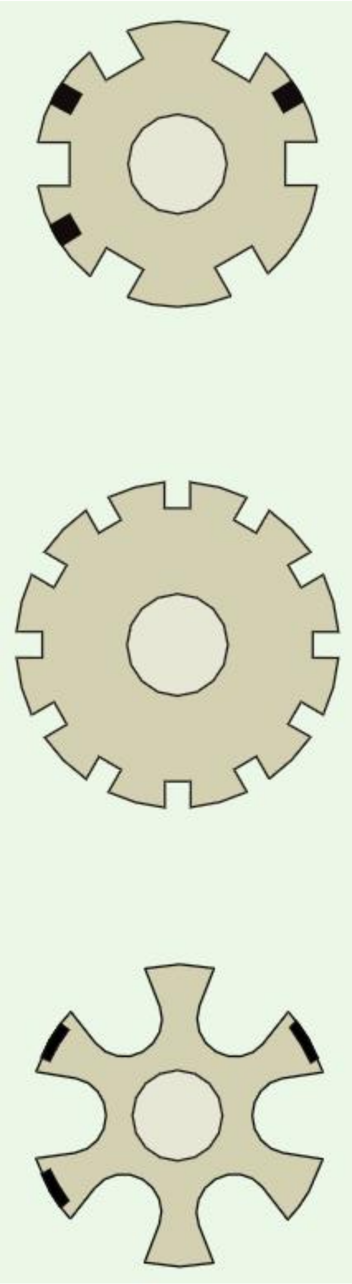

Core
<9 ± 1 µm
Cladding
125 ± 1 µm
Soft acrylate
about 200 µm
Hard acrylate
245 ± 10 µm


Optical fibers
Tube
Strain relief (e.g., Kevlar)
Inner jacket
Sheath
Outer jacket

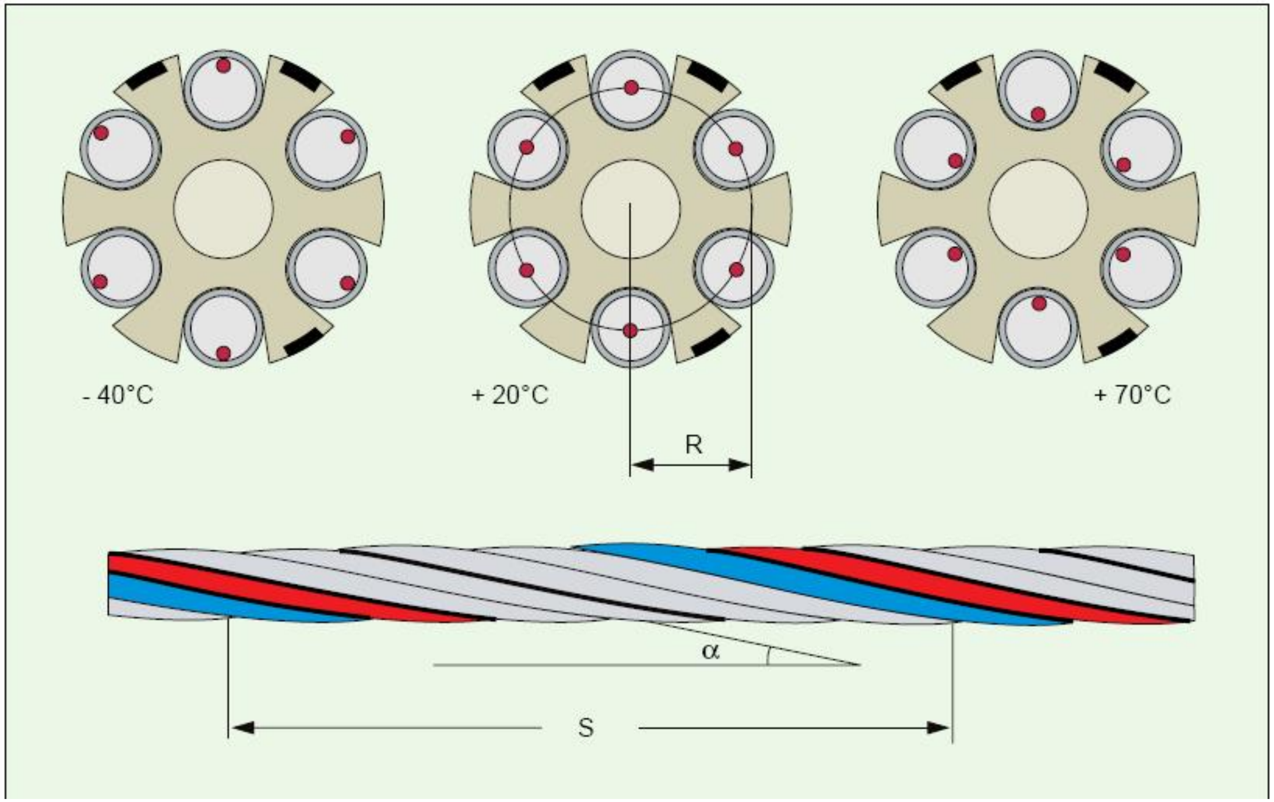
Cabluri

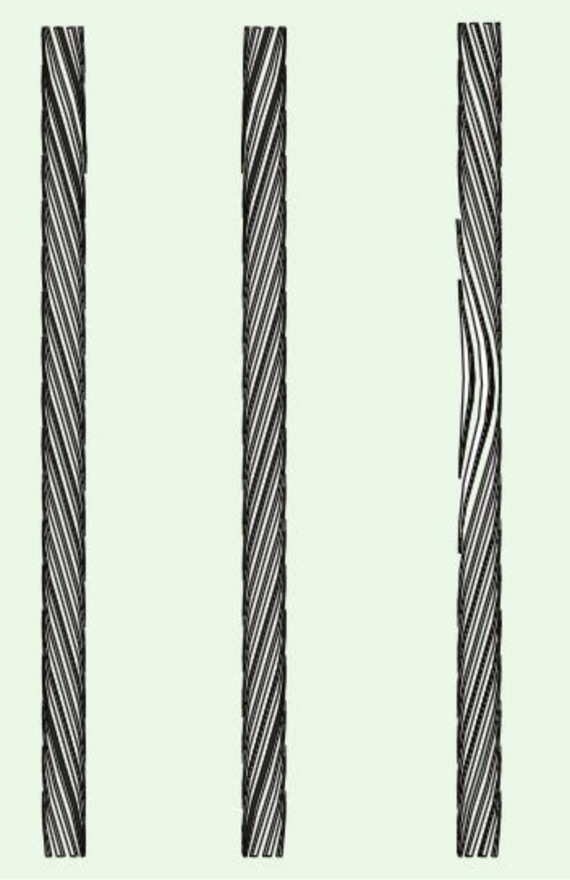






Cabluri

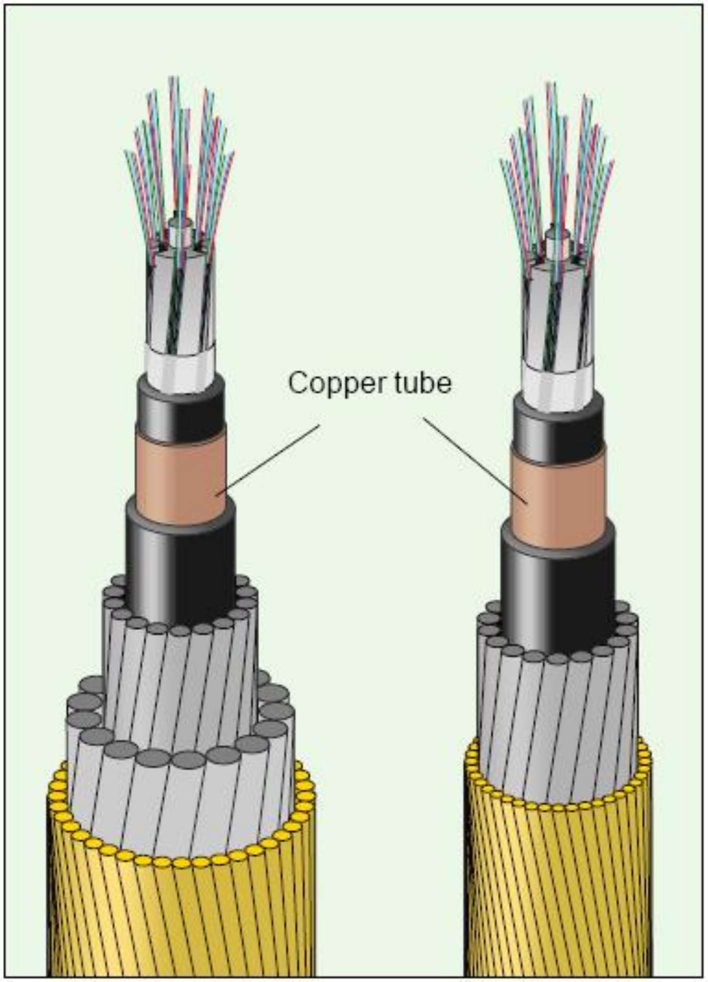


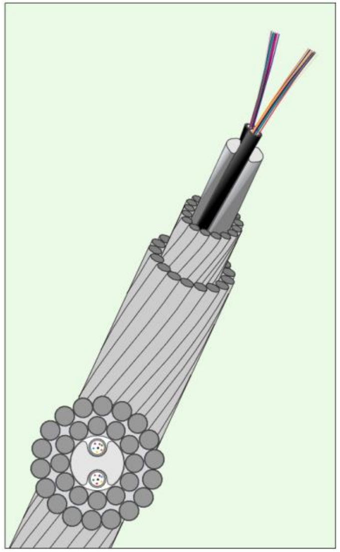


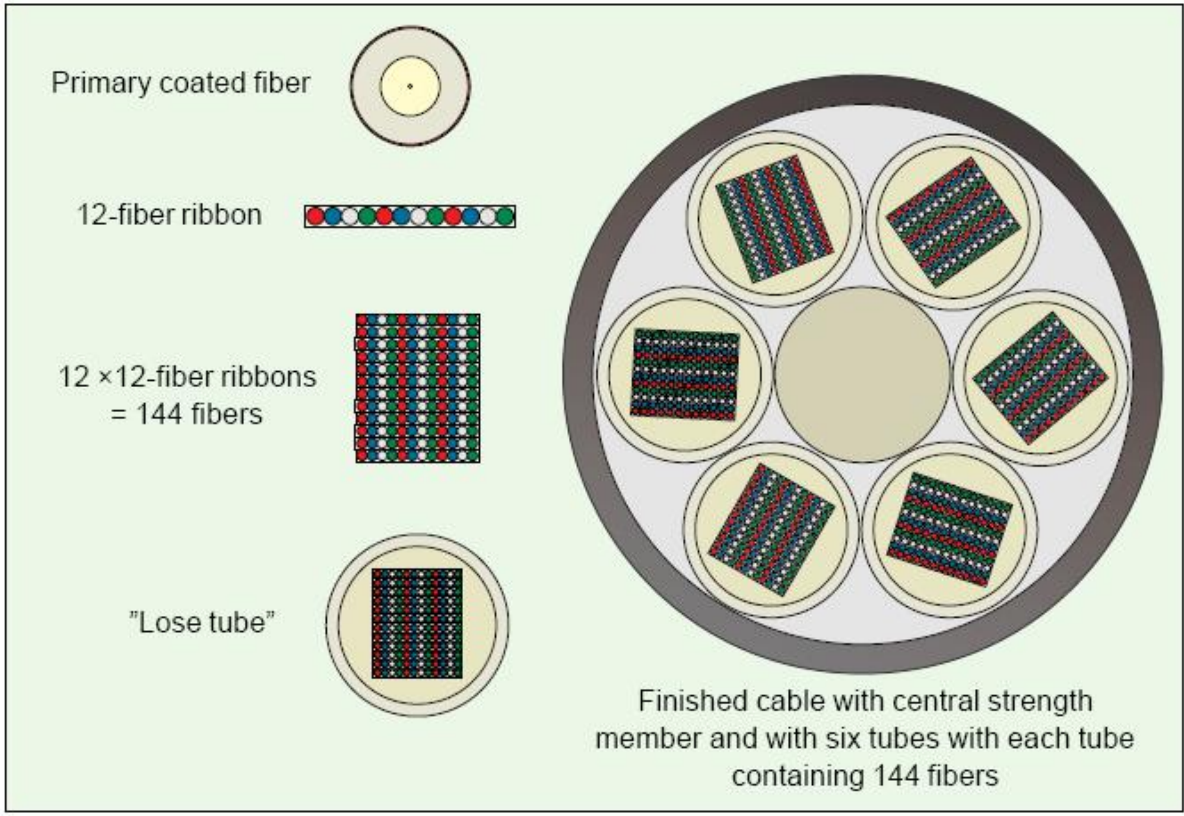
$$S' = S \cdot \sqrt{1 + \left(\frac{2\pi \cdot R}{S} \right)^2}$$

$$\frac{\Delta L}{L_0} = \sqrt{1 + \left(\frac{2\pi \cdot R}{S} \right)^2} - 1$$

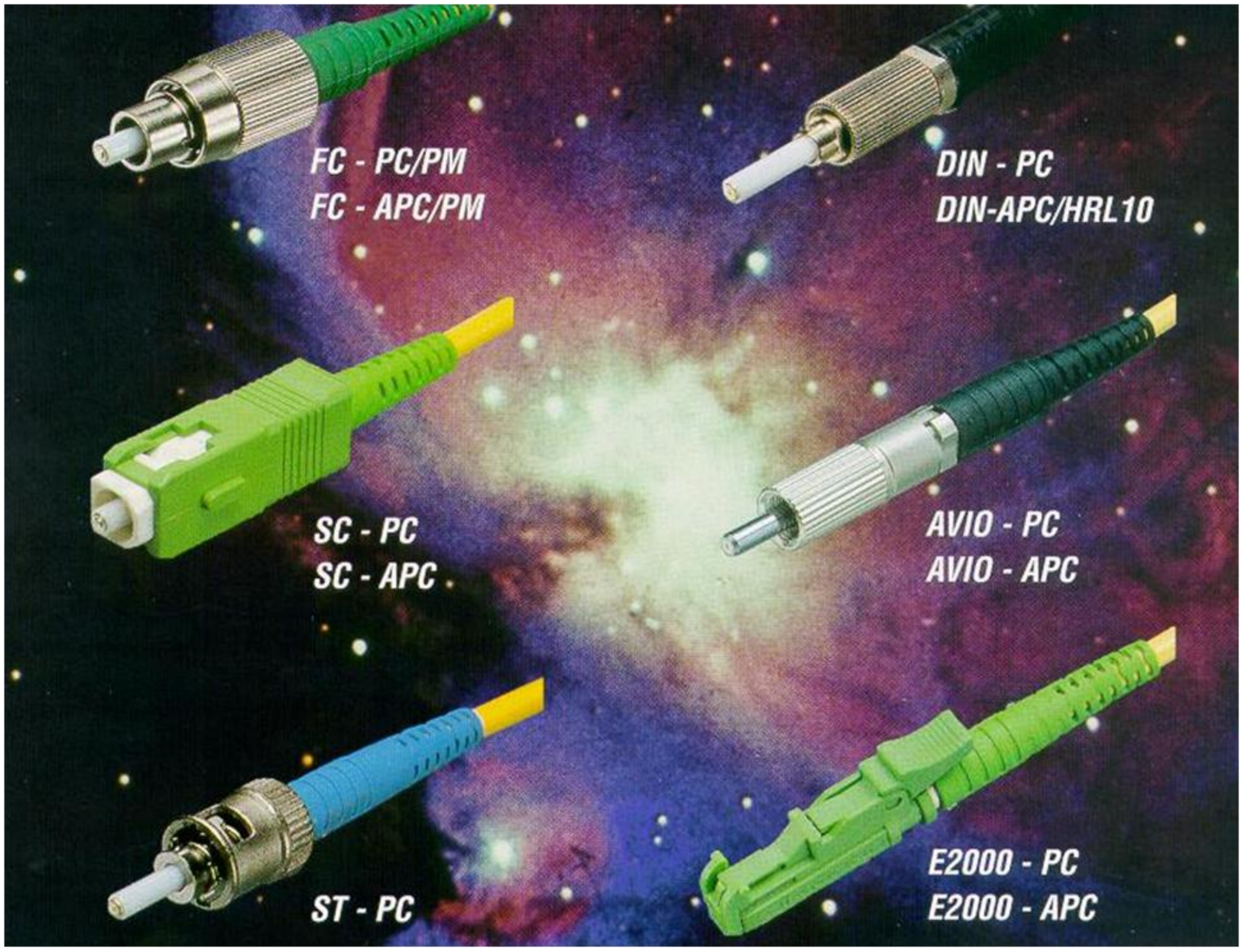
Cabluri


Copper tube



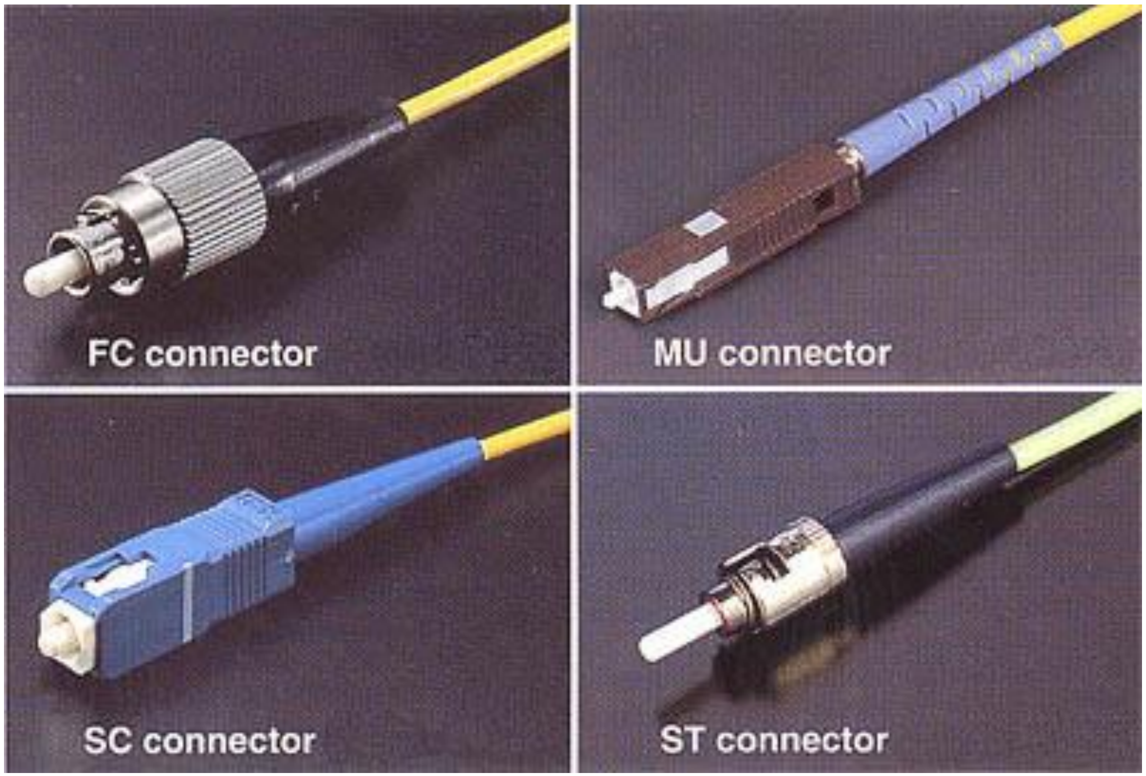

Primary coated fiber
12-fiber ribbon
12 ×12-fiber ribbons
= 144 fibers
"Lose tube"
Finished cable with central strength
member and with six tubes with each tube
containing 144 fibers

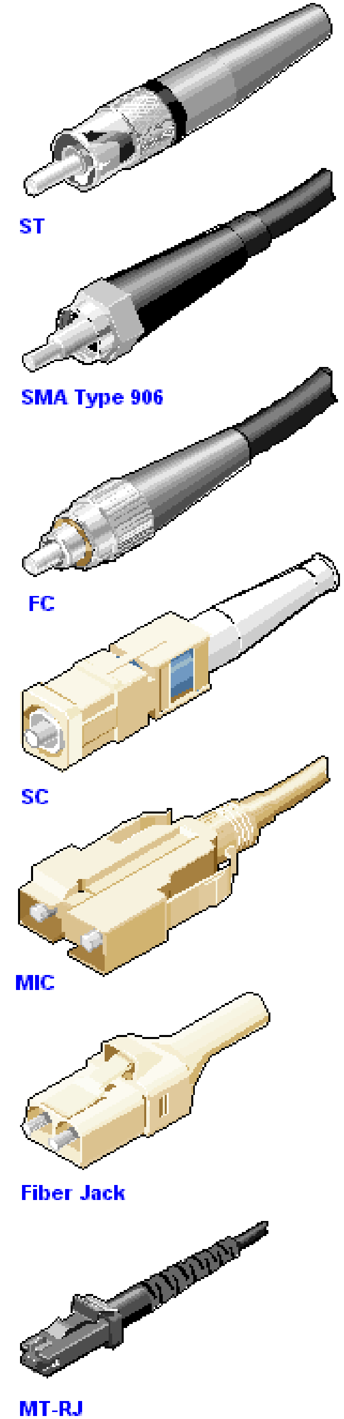
Conectori



FC - PC/PM
FC - APC/PM
DIN - PC
DIN-APC/HRL10
SC - PC
SC - APC
AVIO - PC
AVIO - APC
ST - PC
E2000 - PC
E2000 - APC

Conectori





All fiber-optic connectors use ferrules to hold the ends of the fiber and keep them properly aligned.

The ST connector uses a half-twist bayonet type of lock, while SMA and FC use threaded connections.

The SC uses a push-pull connector similar to common audio and video plugs and sockets.

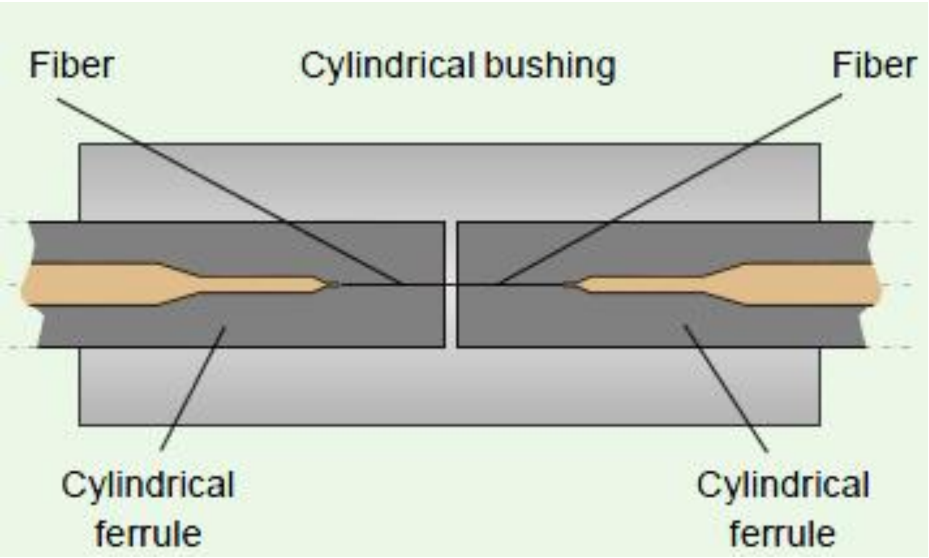
The MIC is the standard FDDI connector.

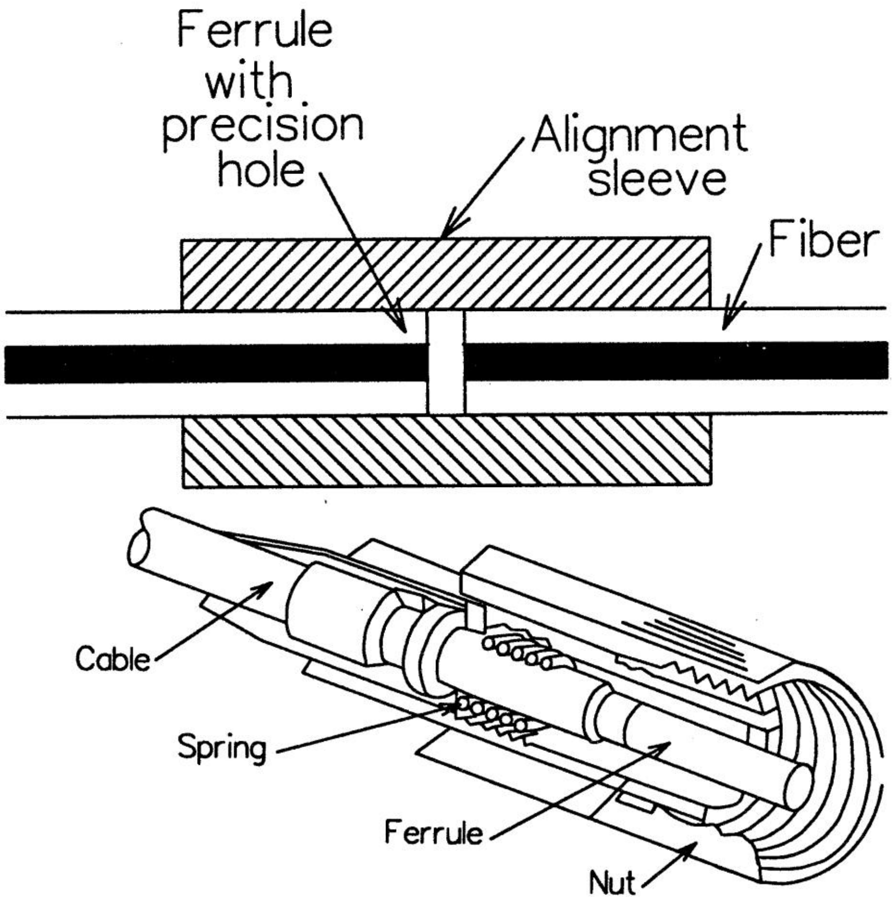
The Fiber Jack connector attaches two fibers in a snap lock connector similar in size and ease of use as an RJ-45 connector.

MT-RJ is a popular connector for two fibers in a very small form factor.

Conectori

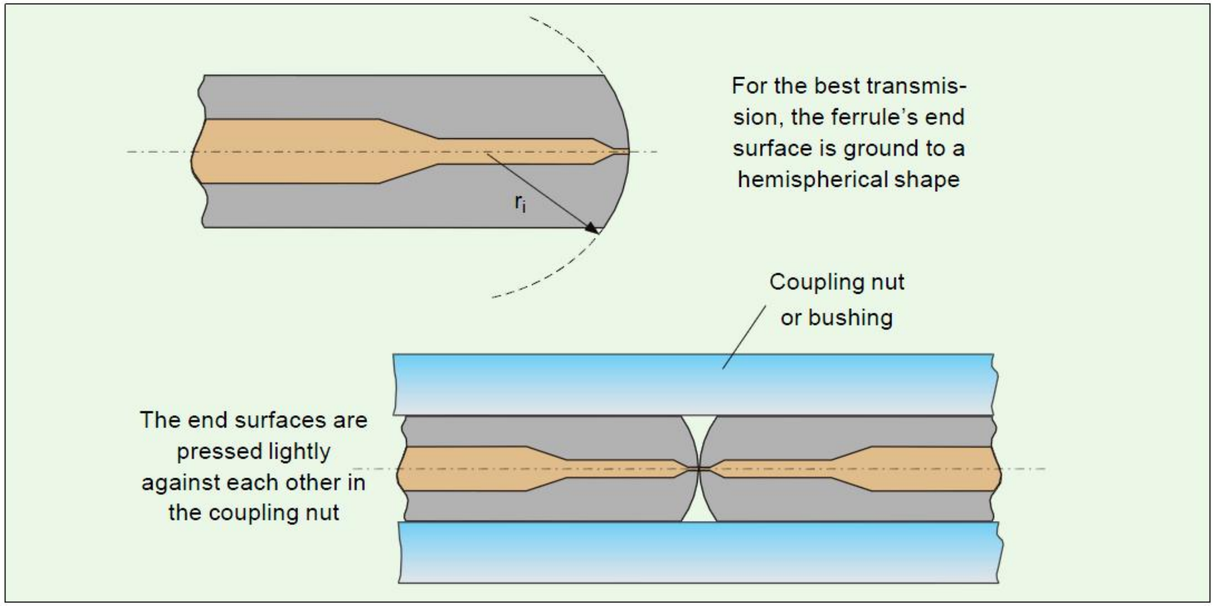
- Verificati http://rf-opto.etti.tuiasi.ro





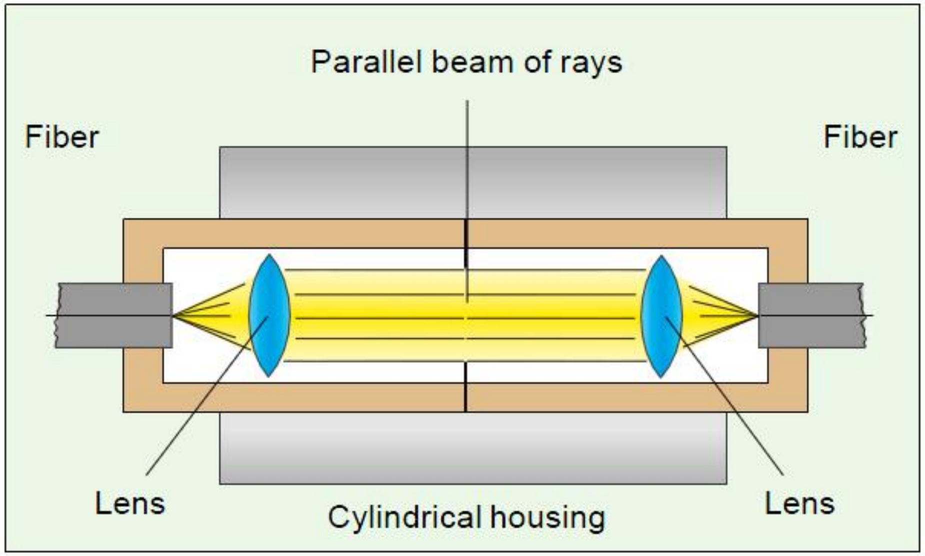
Conectori

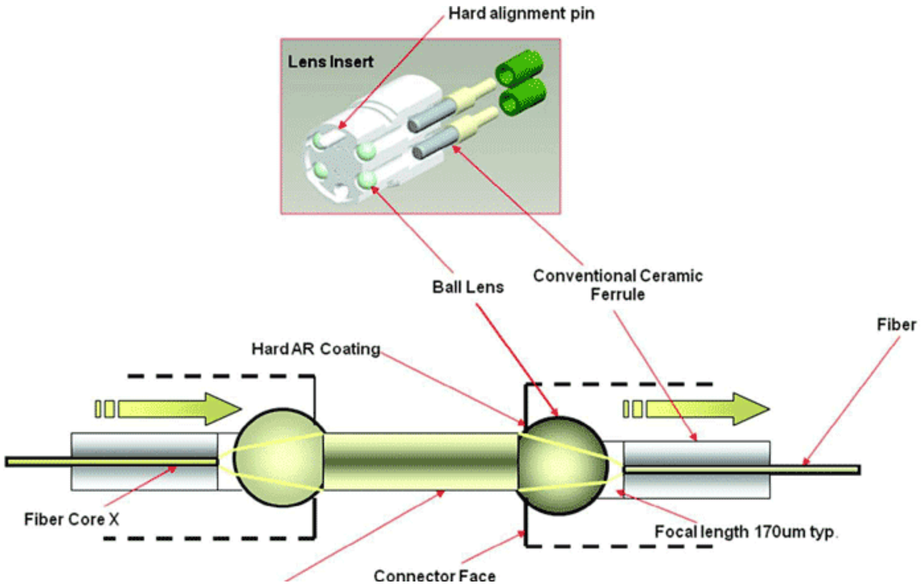
- Ferula semisferica
  - 20mm
  - 60mm



- Conectori multifibra

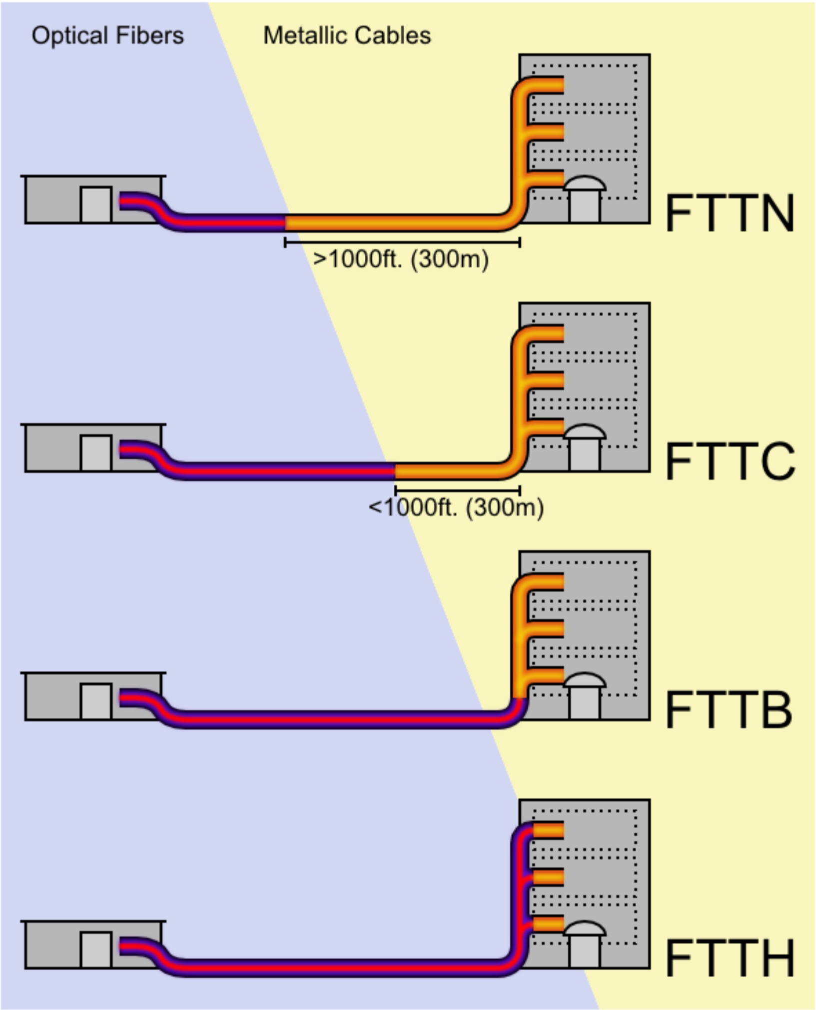
Expanded beam connector





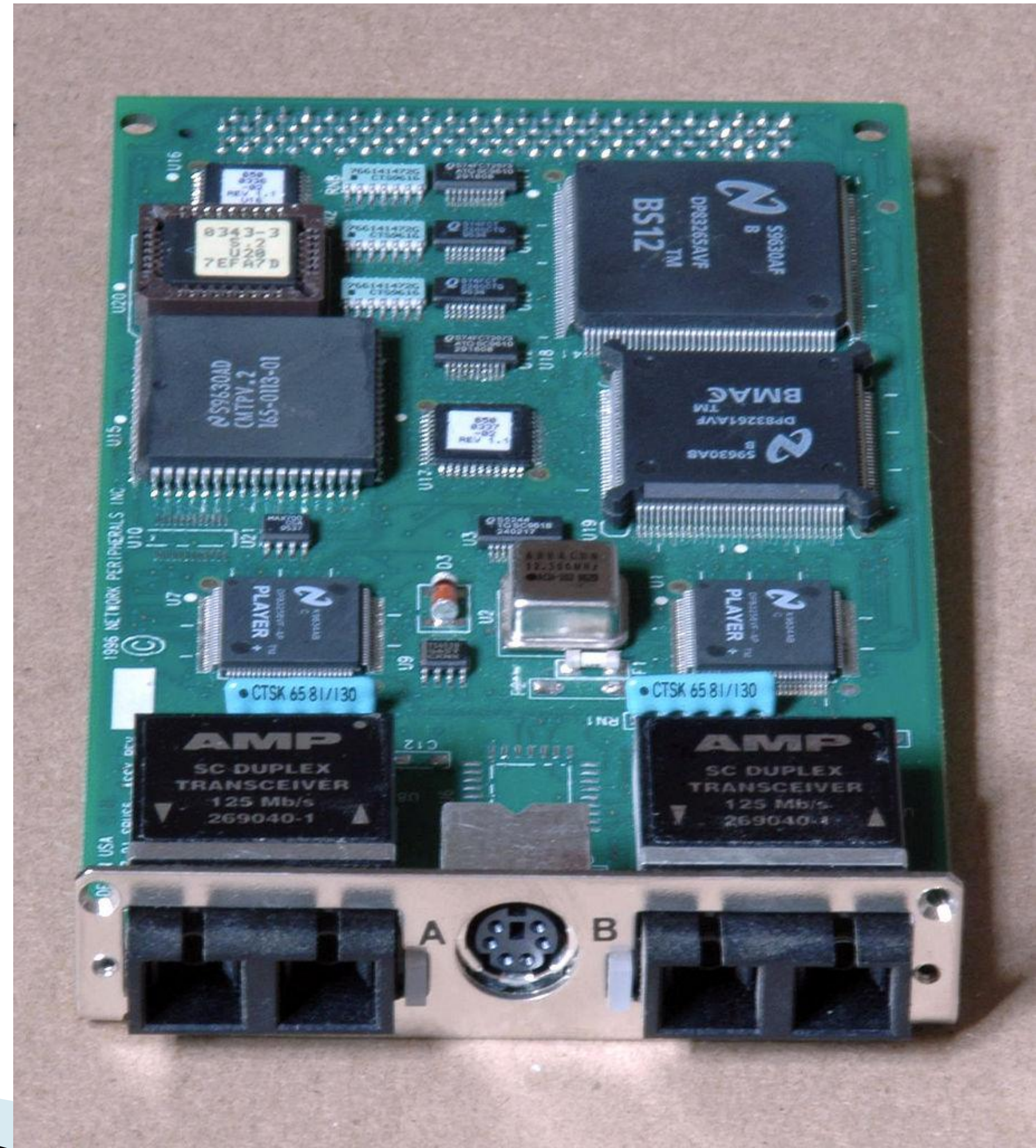
FTTH

- FTTN: Fiber to the node, neighborhood
- FTTC: Fiber to the curb
- FTTB: Fiber to the building
- FTTH: Fiber to the home

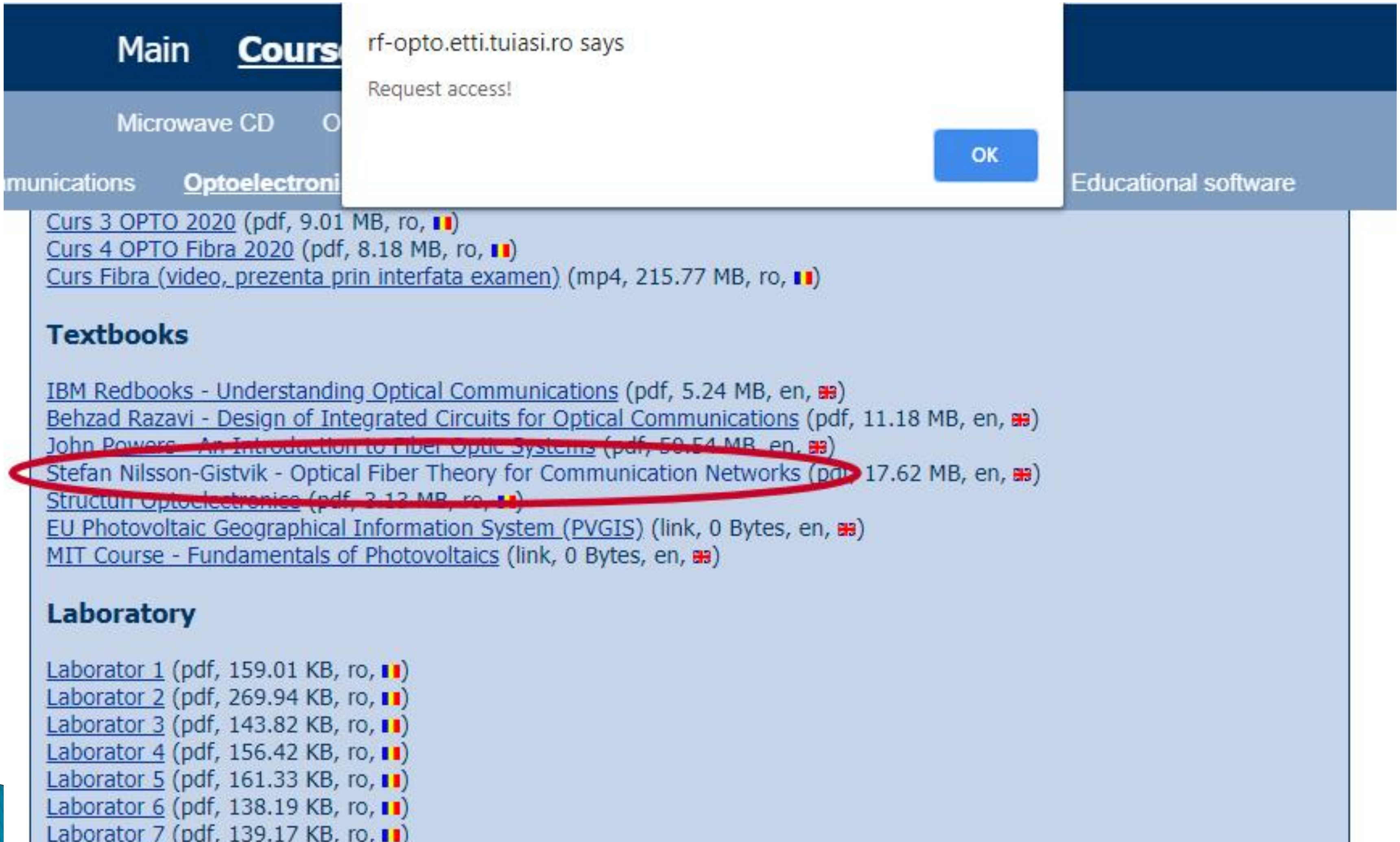


FDDI

- Fiber Distributed Data Interface



Cabluri, Conectori, rf-opto



Dimensionarea unei legături pe fibra optică

Capitolul 6

Cuprins

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- **Elemente de fotometrie şi radiometrie** (mărimi energetice/luminoase)
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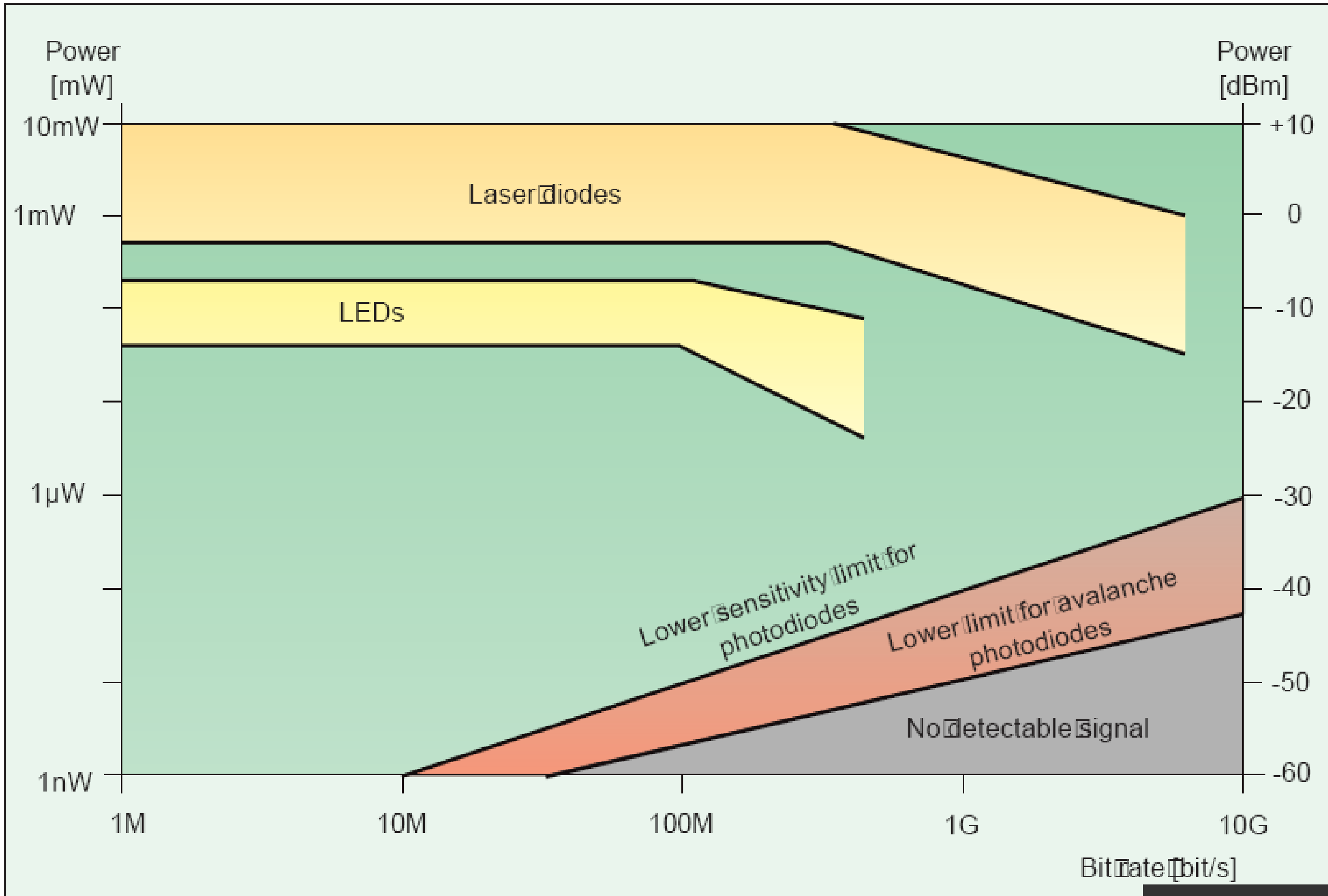
Limite putere/bandă a dispozitivelor optoelectronice

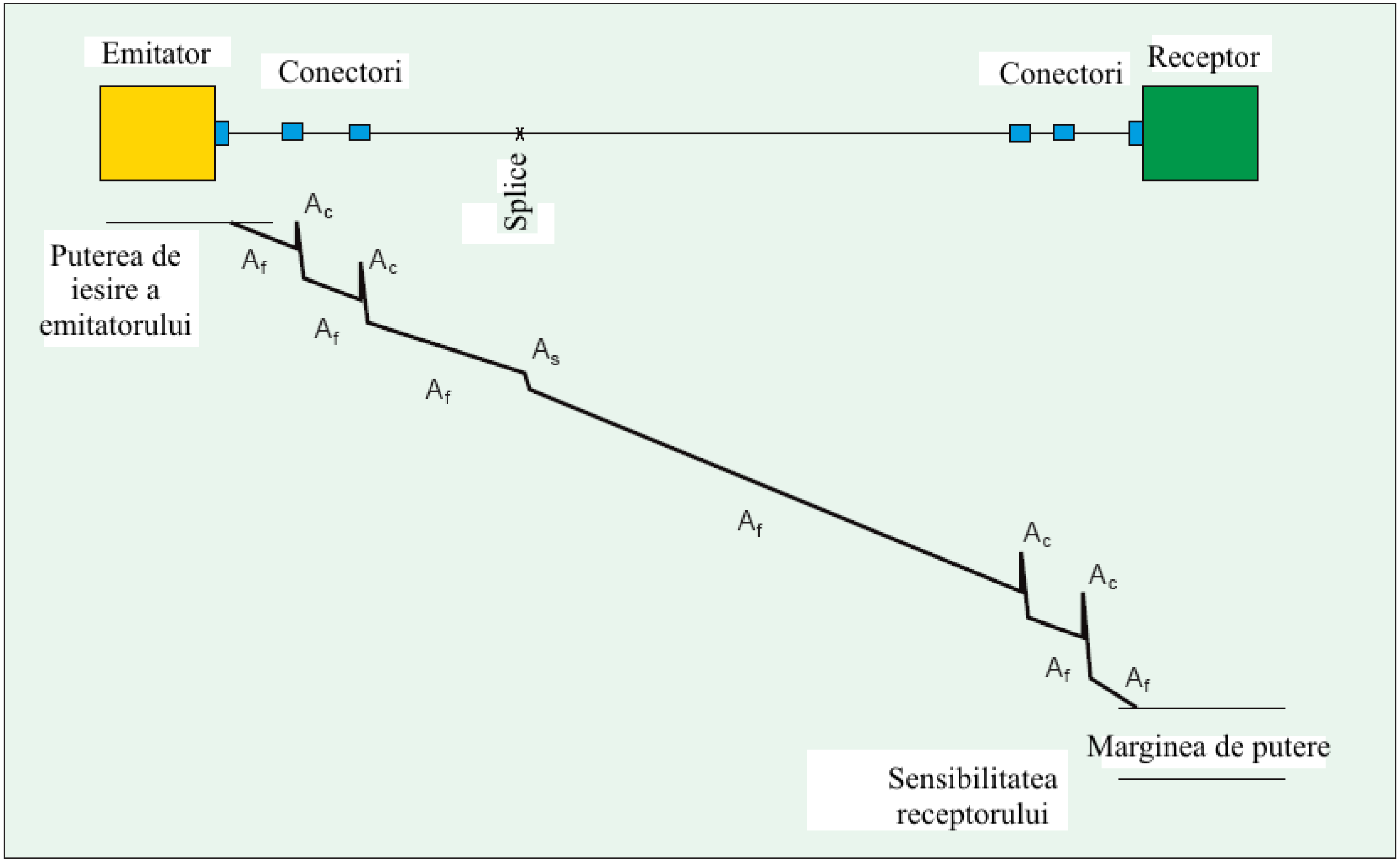


$$dB = 10 \cdot \log_{10}(P_2 / P_1)$$

$$dBm = 10 \cdot \log_{10}(P / 1\ mW)$$

$$[dBm] + [dB] = [dBm]$$

Legatura pe fibra optica

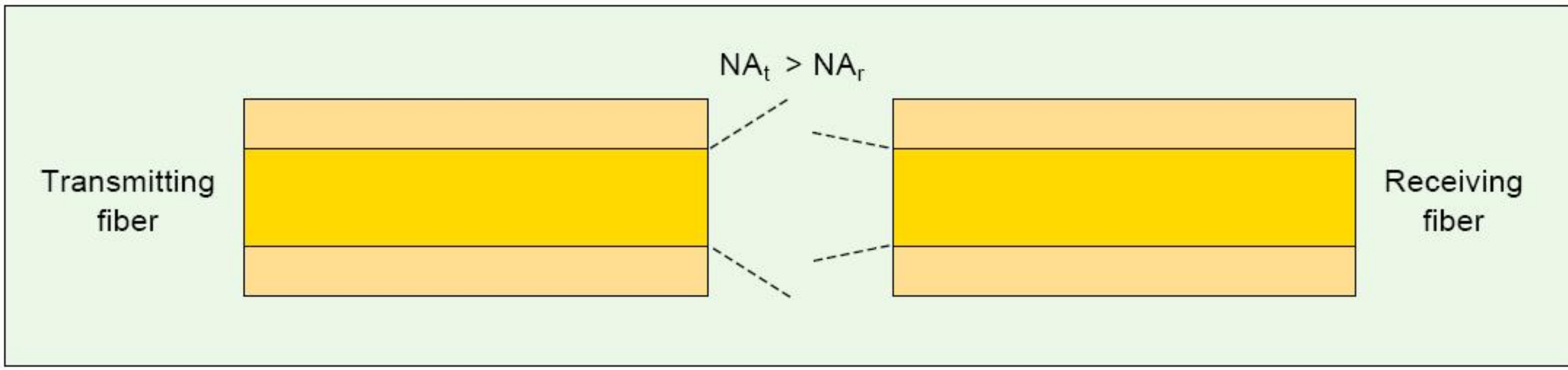


Atenuare

- Macrocurburi
  - utilizator, localizat, dB
- Discontinuitate in fibra
  - utilizator, localizat, dB
- Microcurburi
  - distribuit, tehnologie, dB/km
- Imprastiere
  - distribuit, tehnologie, dB/km
- Absorbtie
  - distribuit, material, dB/km

Pierderi – Apertura numerica

- **Numai** la trecerea de la apertura numerica mai mare la apertura numerica mai mica



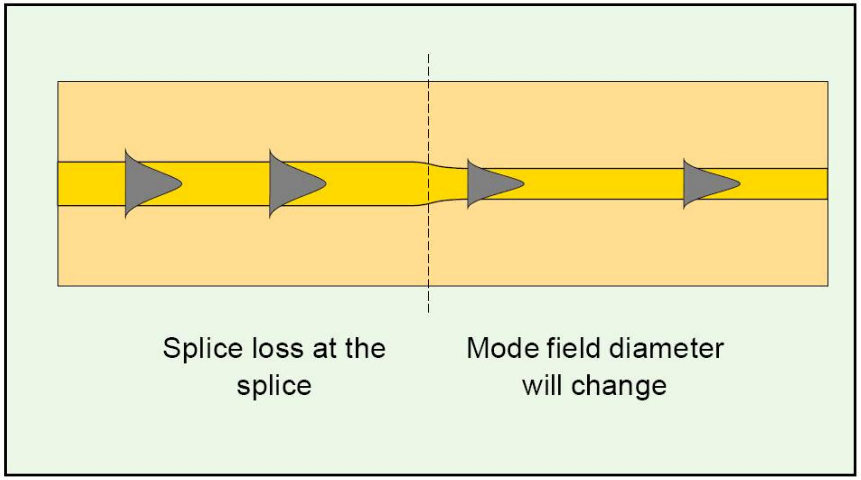
$$\text{Atenuare}_{\text{NA}}[\text{dB}] = -10 \cdot \log_{10}\left(\frac{NA_r}{NA_t}\right)^2$$

numai pentru $NA_r < NA_t$

$$\text{Atenuare}_{\text{NA}}[\text{dB}] > 0$$

Pierderi – Diametrul miezului

- **Numai** la trecerea de la diametru mai mare la diametru mai mic (multimod)
- **Bidirectional** (monomod)



- multimod

$$Atenuare_{\Phi}[dB] = -10 \cdot \log_{10}\left(\frac{\phi_r}{\phi_t}\right)^2$$

numai pentru $\Phi_r < \Phi_t$

- monomod

$$Atenuare_{\Phi}[dB] = -20 \cdot \log_{10}\left(\frac{2 \cdot w_1 \cdot w_2}{w_1^2 + w_2^2}\right)$$

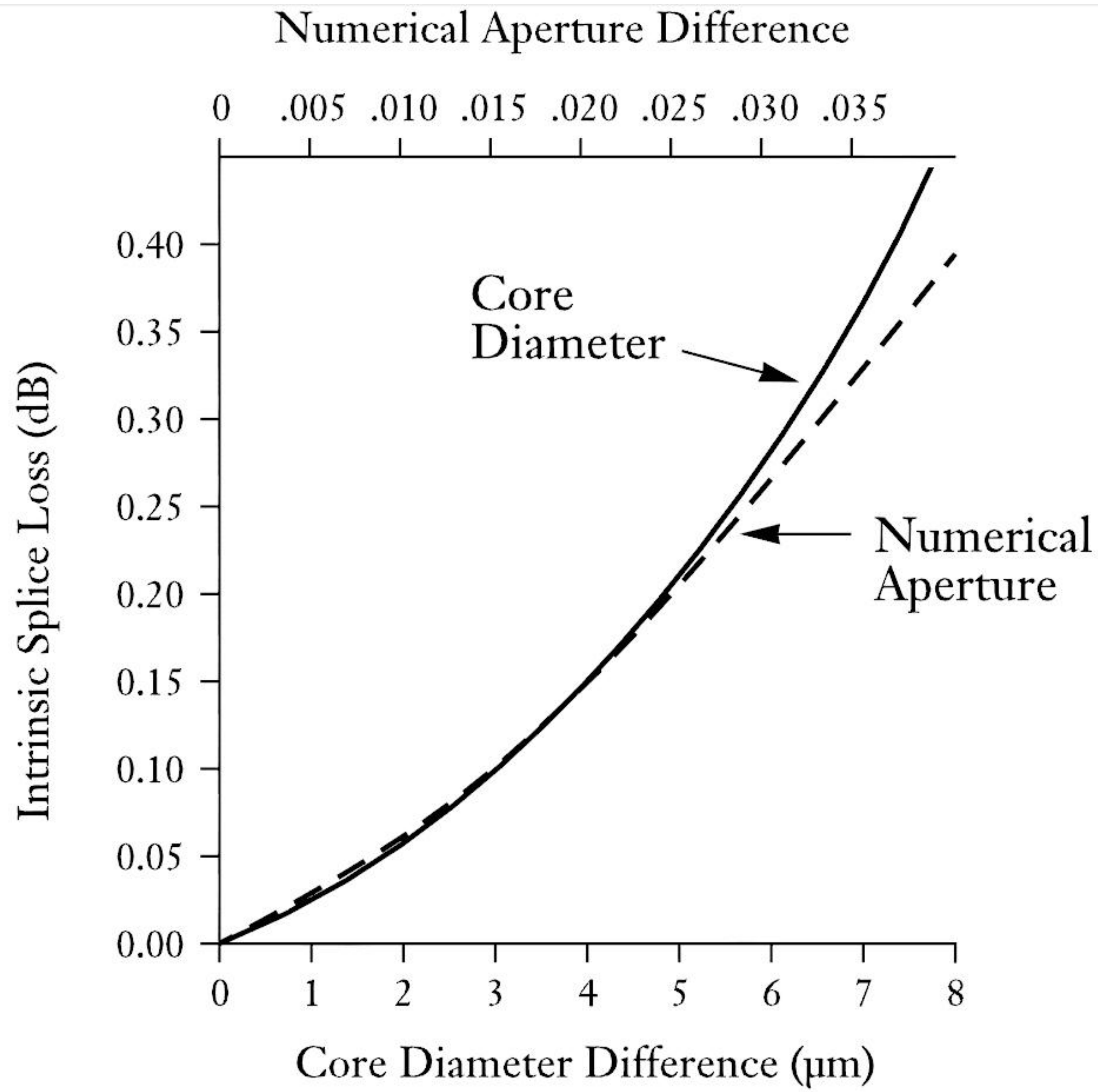
bidirectional $\forall w_1, w_2$

w = MFD !!

$$Atenuare_{\Phi}[dB] > 0$$

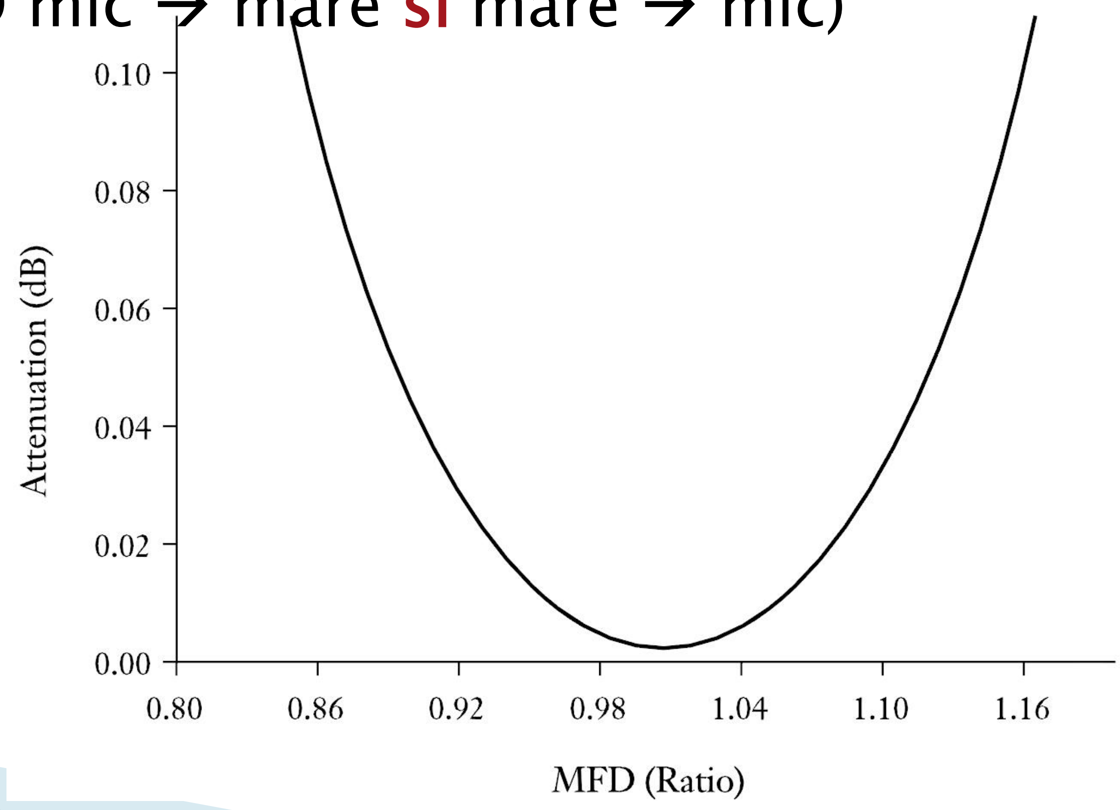
Pierderi

- multimod



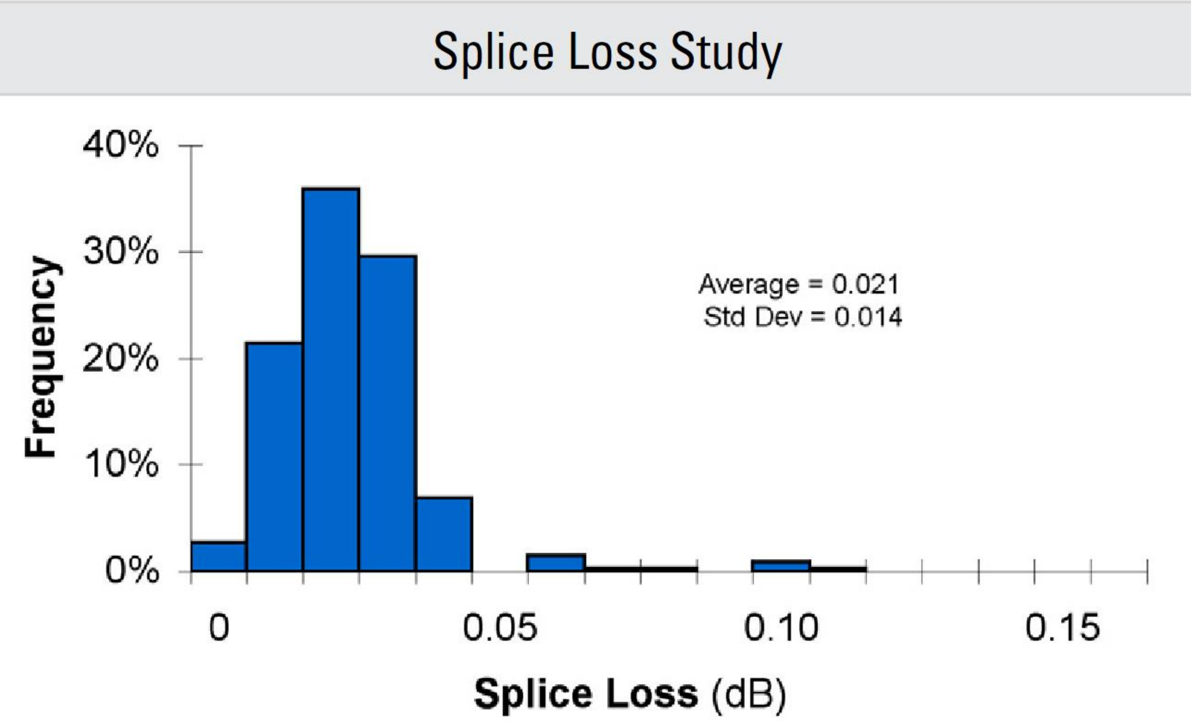
Pierderi

- monomod
  - predomina pierderile datorate diferentelor de MFD
  - se poate neglija NA
  - **Bidirectional** (MFD mic → mare **si** mare → mic)

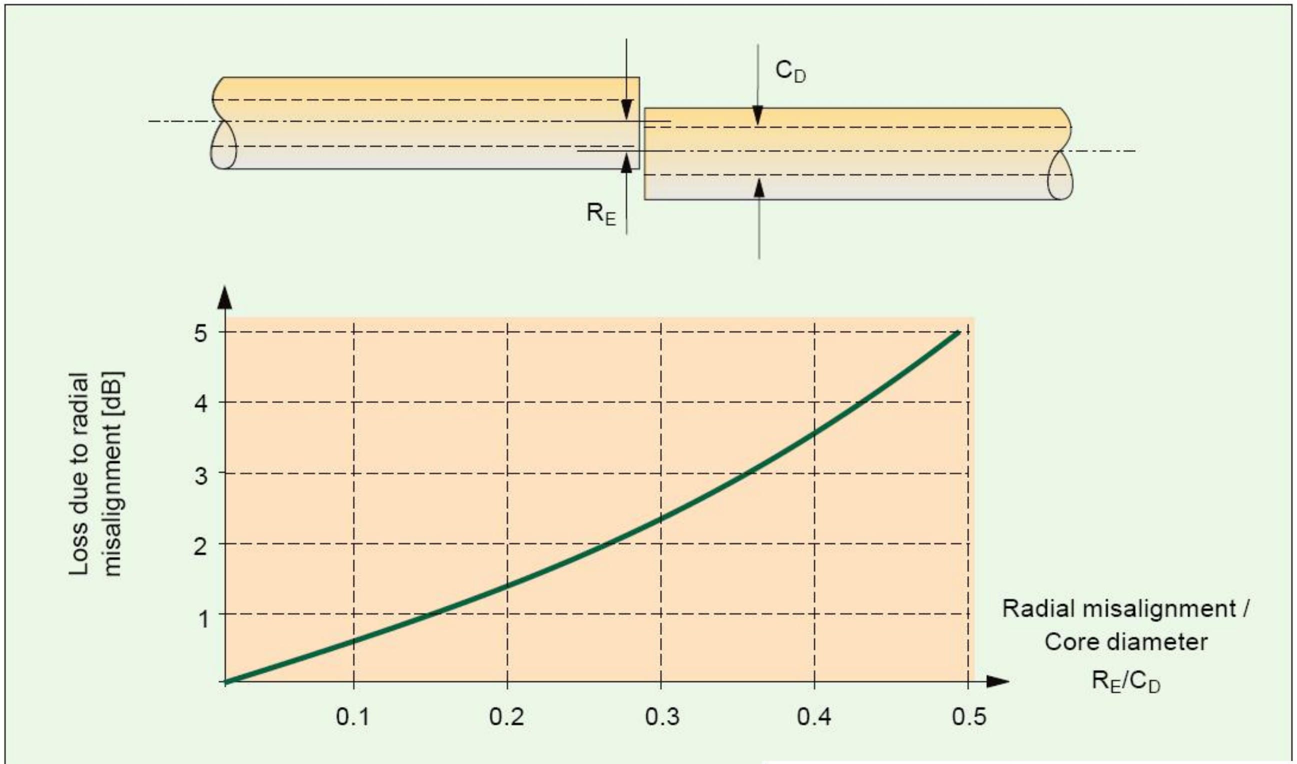


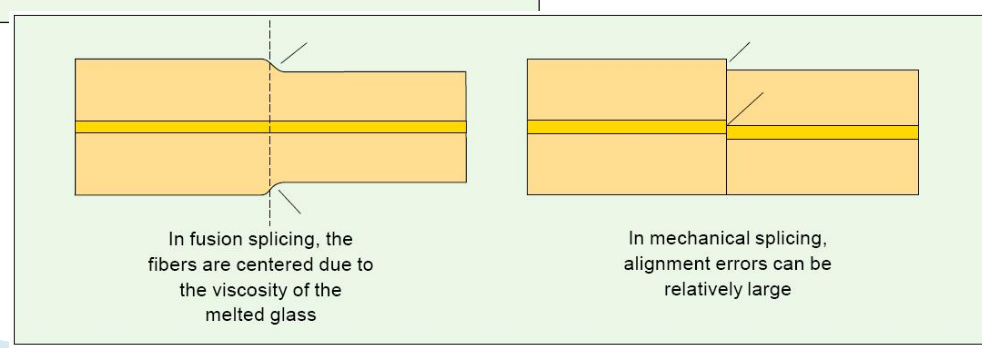
Pierderi

- monomod
- tipic: cel mai dezavantajos pentru MFD = 9.3±0.5μm → A=0.04dB

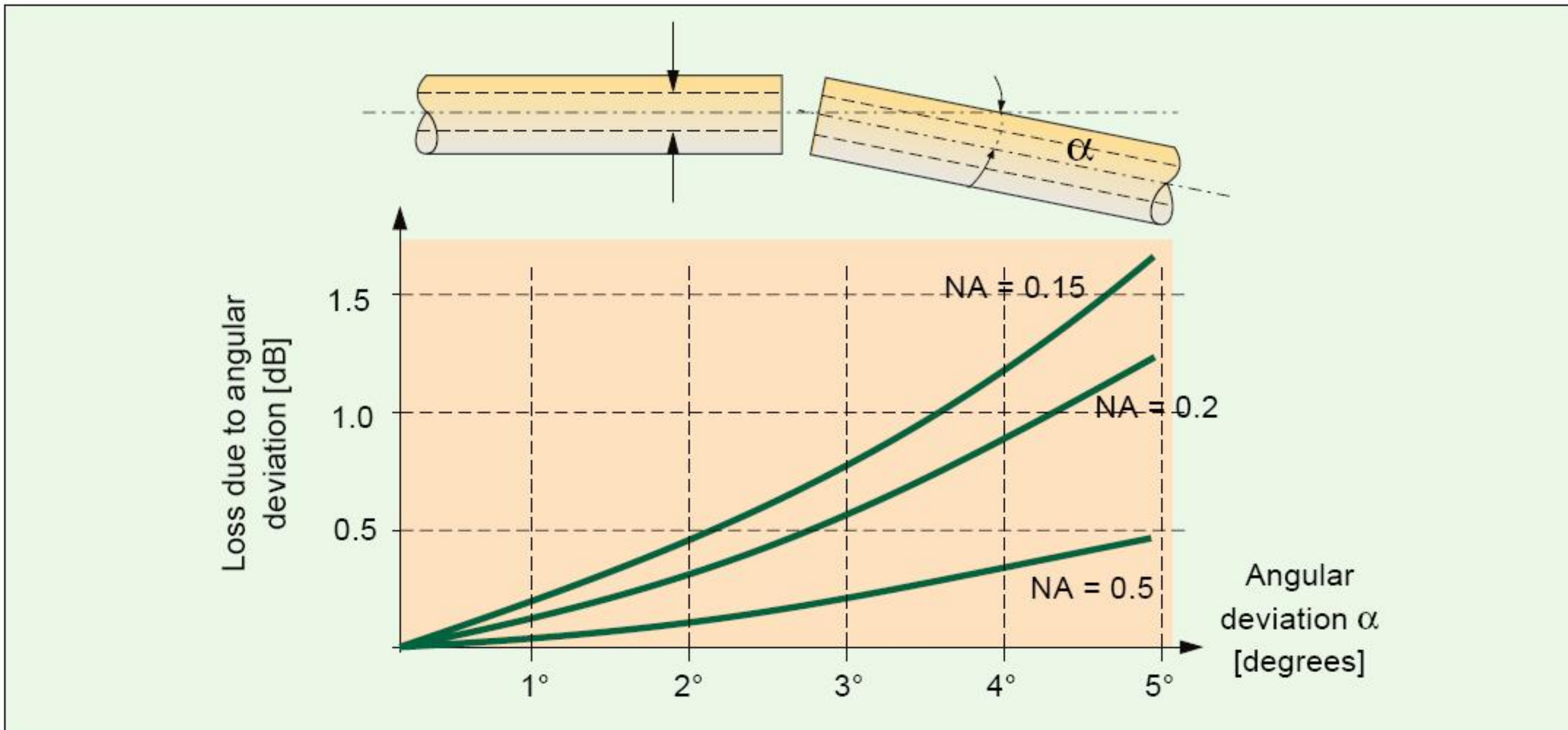


Pierderi – Nealinierea axelor



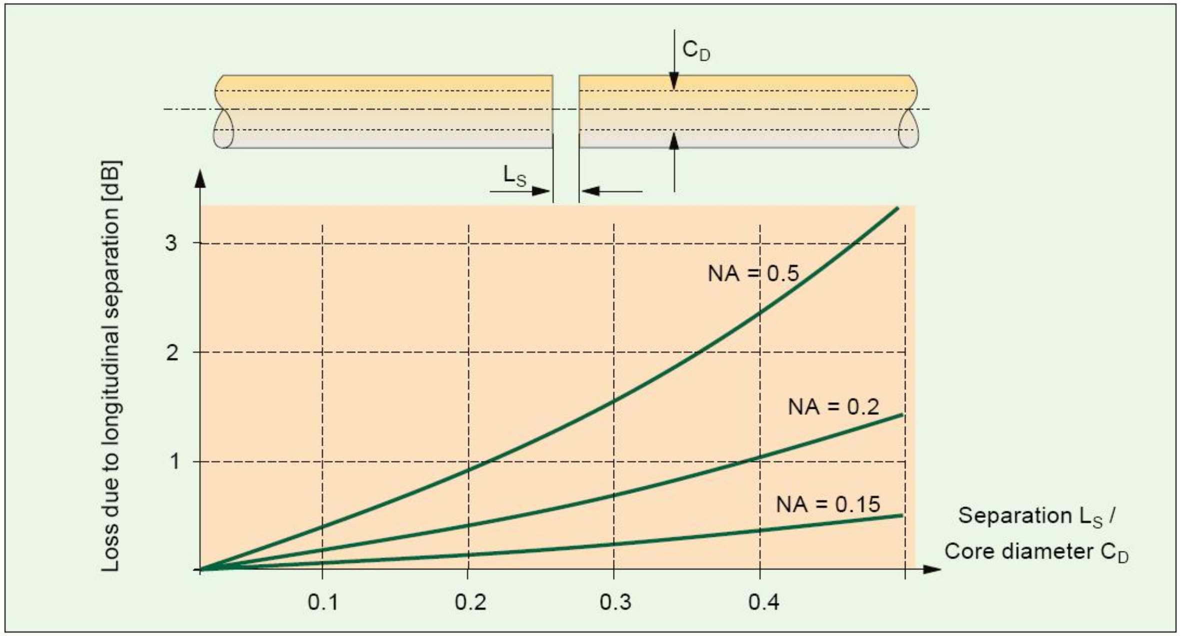


Pierderi – unghi



Pierderi – distanta

- Se foloseste un gel cu indice de refractie egal cu al fibrelor
- Se aduna pierderile generate de reflexie pe o lamela (pana la 16%)



Exemplu

- Trebuie să realizaţi o legătură pe fibră optică pe o distanţă de 50 km la o viteză de 1Gb/s.

Emiţători: = 1.5mW (Δλ=2nm, diverse λ)	NA = 0.17	Φ = 13μm
Pierderi splice (tehnologie)	0.15 dB/splice	
Pierderi conector	0.5 dB/conector	
Cablu conexiune: L = 20m	NA = 0.12	fibră: 11/125 μm
Cablu conexiune: L = 20m	NA = 0.15	fibră: 11/125 μm
Fibra 1	8 X 5km	
Fibra 2	4 X 10km	
Fibra 3	8 X 5km	
Fibra 4	4 X 10km	
Receptor: Sensitivitate = 1μW	NA = 0.25	Φ = 30μm

Catalog

Optical Specifications

Fibra nr. 3

Fiber Attenuation

Maximum Attenuation

Wavelength (nm)	Maximum Value* (dB/km)
1310	0.33 – 0.35
1383**	0.31 – 0.35
1490	0.21 – 0.24
1550	0.19 – 0.20
1625	0.20 – 0.23

*Maximum specified attenuation value available within the stated ranges.
**Attenuation values at this wavelength represent post-hydrogen aging performance.
Alternate attenuation offerings available upon request.

Attenuation vs. Wavelength

Range (nm)	Ref. λ (nm)	Max. α Difference (dB/km)
1285 – 1330	1310	0.03
1525 – 1575	1550	0.02

The attenuation in a given wavelength range does not exceed the attenuation of the reference wavelength (λ) by more than the value α.

Macrobend Loss

Mandrel Diameter (mm)	Number of Turns	Wavelength (nm)	Induced Attenuation* (dB)
32	1	1550	≤0.03
50	100	1310	≤0.03
50	100	1550	≤0.03
60	100	1625	≤0.03

*The induced attenuation due to fiber wrapped around a mandrel of a specified diameter.

Point Discontinuity

Wavelength (nm)	Point Discontinuity (dB)
1310	≤0.05
1550	≤0.05

Cable Cutoff Wavelength (λ_{ccf})

$\lambda_{ccf} \leq 1260$ nm

Mode-Field Diameter

Wavelength (nm)	MFD (µm)
1310	9.4 ± 0.4
1550	10.6 ± 0.5

Dispersion

Wavelength (nm)	Dispersion Value [ps/(nm•km)]
1550	≤18
1625	≤23

Zero Dispersion Wavelength (λ_0): 1310 nm $\leq \lambda_0 \leq$ 1324 nm
Zero Dispersion Slope (S_0): ≤ 0.092 ps/(nm^2•km)

Polarization Mode Dispersion (PMD)

	Value (ps/√km)
PMD Link Design Value	≤0.06*
Maximum Individual Fiber	≤0.2

*Complies with IEC 60794-3: 2001, Section 5.5, Method 1, September 2001.

The PMD link design value is a term used to describe the PMD of concatenated lengths of fiber (also known as PMD_Q). This value represents a statistical upper limit for total link PMD. Individual PMD values may change when cabled. Corning's fiber specification supports network design requirements for a 0.5 ps/√km maximum PMD.

Dimensional Specifications

Glass Geometry

Fiber Curl	≥ 4.0 m radius of curvature
Cladding Diameter	125.0 ± 0.7 µm
Core-Clad Concentricity	≤ 0.5 µm
Cladding Non-Circularity	≤ 0.7%

Coating Geometry

Coating Diameter	245 ± 5 µm
Coating-Cladding Concentricity	<12 µm

Environmental Specifications

Environmental Test	Test Condition	Induced Attenuation 1310 nm, 1550 nm & 1625 nm (dB/km)
Temperature Dependence	-60°C to +85°C*	≤0.05
Temperature Humidity Cycling	-10°C to +85°C* up to 98% RH	≤0.05
Water Immersion	23°± 2°C	≤0.05
Heat Aging	85°± 2°C*	≤0.05

*Reference temperature = +23°C

Operating Temperature Range: -60°C to +85°C

Mechanical Specifications

Proof Test

The entire fiber length is subjected to a tensile stress ≥100 kpsi (0.7 GPa)*.
*Higher proof test levels available.

Length

Fiber lengths available up to 50.4* km/spool.
*Longer spliced lengths available.

Performance Characterizations

Characterized parameters are typical values.

Core Diameter	8.2 µm
Numerical Aperture	0.14 *NA is measured at the one percent power level of a one-dimensional far-field scan at 1310 nm.*
Zero Dispersion Wavelength (λ_0)	1317 nm
Zero Dispersion Slope (S_0)	0.088 ps/(nm^2•km)
Effective Group Index of Refraction (N_{eff})	1310 nm: 1.4670 1550 nm: 1.4677
Fatigue Resistance Parameter (N_d)	20
Coating Strip Force	Dry: 0.6 lbs. (3N) Wet, 14-day room temperature: 0.6 lbs. (3N)
Rayleigh Backscatter Coefficient (for 1 ns Pulse Width)	1310 nm: -77 dB 1550 nm: -82 dB
Stimulated Brillouin Scattering Threshold	20 dBm[1]

Notes:
(1) When characterized with a transmitter specifying 17 dBm SBS threshold over standard single-mode fiber. While absolute SBS threshold is a function of distance and signal format, NexCor fiber offers a 3 dB improvement over standard single-mode fiber independent of these variables.

Formulas

Dispersion

$$\text{Dispersion} = D(\lambda) := \frac{S_0}{4}\left[\lambda - \frac{\lambda_0^4}{\lambda^3}\right] \text{ps/(nm•km)},$$

for 1200 nm ≤ λ ≤ 1625 nm

λ = Operating Wavelength

Cladding Non-Circularity

$$\text{Cladding Non-Circularity} = \left[1 - \frac{\text{Min. Cladding Diameter}}{\text{Max. Cladding Diameter}}\right] \times 100$$

How to Order

Contact your sales representative, or call the Optical Fiber Customer Service Department:
Ph: 607-248-2000 (U.S. and Canada)
+44-1244-287-437 (Europe)
Email: opticalfibcs@corning.com
Please specify the fiber type, attenuation and quantity when ordering.

Corning Incorporated
www.corning.com/opticalfiber
One Riverfront Plaza
Corning, NY 14831
U.S.A.
Ph: 800-525-2524 (U.S. and Canada)
607-786-8125 (International)
Fx: 800-539-3632 (U.S. and Canada)
607-786-8344 (International)
Email: cofic@corning.com

Europe
Ph: 00 800 6620 6621 (U.K., Ireland, Italy, France, Germany, The Netherlands, Spain and Sweden)
+1 607 786 8125 (All Other Countries)
Fx: +1 607 786 8344

Asia Pacific
Australia
Ph: 1-800-148-690
Fx: 1-800-148-568
Indonesia
Ph: 001-803-015-721-1261
Fx: 001-803-015-721-1262
Malaysia
Ph: 1-800-80-3156
Fx: 1-800-80-3155
Philippines
Ph: 1-800-1-116-0338
Fx: 1-800-1-116-0339
Singapore
Ph: 800-1300-955
Fx: 800-1300-956
Thailand
Ph: 001-800-1-3-721-1263
Fx: 001-800-1-3-721-1264

Latin America
Brazil
Ph: 000817-762-4732
Fx: 000817-762-4996
Mexico
Ph: 001-800-235-1719
Fx: 001-800-339-1472
Venezuela
Ph: 800-1-4418
Fx: 800-1-4419

Greater China
Email: GCCofic@corning.com
Beijing
Ph: (86) 10-6505-5066
Fx: (86) 10-6505-5077
Hong Kong
Ph: (852) 2807-2723
Fx: (852) 2807-2152
Shanghai
Ph: (86) 21-3222-4668
Fx: (86) 21-6288-1575
Taiwan
Ph: (886) 2-2716-0338
Fx: (886) 2-2716-0339

Intrebari

- (1p) Ce lungime de undă veţi alege pentru emiţător? Justificaţi.
- (2p) Alegeţi fibrele pe care le veţi utiliza. Justificaţi. Realizaţi schiţa legăturii
- (1p) Puteţi realiza o legătură funcţională? Justificaţi.

Zero Dispersion Wavelength (λ_0)	1317 nm
Zero Dispersion Slope (S_0)	0.088 ps/(nm^2•km)

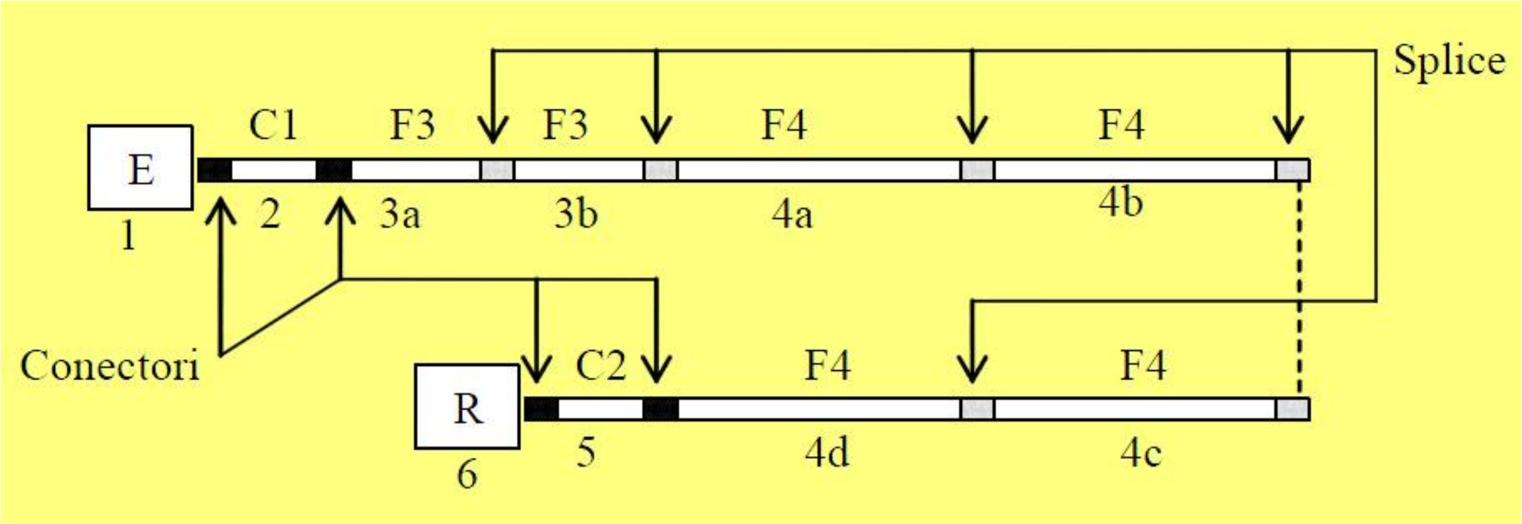
Legatura

- Bilantul puterilor

Maximum Attenuation	
Wavelength (nm)	Maximum Value* (dB/km)
1310	0.33 – 0.35
1383**	0.31 – 0.35
1490	0.21 – 0.24
1550	0.19 – 0.20
1625	0.20 – 0.23

$$A_{tot}[\mathrm{dB}] = \sum_i A_i[\mathrm{dB}]$$

$$P_e[\mathrm{dBm}] \pm A_{tot}[\mathrm{dB}] \geq S_r[\mathrm{dBm}] + M[\mathrm{dB}]$$



Sistem

- 1. Emitator
- 2. Cablu 1 de conexiune
- 3. Fibra 3 (2 cabluri a 5 km fiecare: 3a,3b)
- 4. Fibra 4 (4 cabluri a 10 km fiecare: 4a,4b,4c,4d)
- 5. Cablu 2 de conexiune
- 6. Receptor

Atenuare

- Distribuita
  - microcurburi
  - imprastiere
  - absorbtie
- Localizata
  - macrocurburi
  - conectori
  - splice
  - tranzitii

$$Atenuare_D[dB/km] = \frac{Pierderi[dB]}{lungime[km]}$$

$$Atenuare_L[dB] = Pierderi[dB]$$

$$A_{TOT}[dB] = A_L[dB] + A_D[dB/km] \cdot L[km]$$

Pierderi

- Atenuare in fibra
- Atenuare datorata conectorilor
- Atenuare datorata splice-urilor
- Atenuare datorata diferentelor de apertura numerica
  - apare **numai** la trecerea de la un dispozitiv cu NA mai mare la un dispozitiv cu NA mai mic
  - **neglijabil** intre 2 fibre monomod sudate
- Atenuare datorata diferentelor de diametru
  - apare **numai** la trecerea de la un dispozitiv cu diametru mai mare la un dispozitiv cu diametru mai mic
  - **bidirectional** la fibre monomod sudate

Dispersie

$$\Delta\tau_{\mathrm{mod}} \cong \frac{L\cdot n_2\cdot\Delta}{2\sqrt{3}\cdot c} \approx \frac{L\cdot NA^2}{4\sqrt{3}\cdot c\cdot n_2}$$

$$\Delta\tau_{\mathrm{mod}} \cong \frac{L\cdot n_2\cdot\Delta^2}{4\sqrt{3}\cdot c} \cong \frac{L\cdot NA^4}{16\sqrt{3}\cdot c\cdot n_2^3}$$

$$\Delta\tau_{cr} = D(\lambda)\cdot\Delta\lambda\cdot L$$

$$\mathrm{D}(\lambda) = \frac{\mathrm{S}_0}{4}\cdot\left(\lambda - \frac{\lambda_0^4}{\lambda^3}\right)$$

$$\Delta\tau_{tip} = \sum_i \Delta\tau_i$$

$$\Delta\tau_{tot} = \sqrt{\Delta\tau_{cr}^2 + \Delta\tau_{\mathrm{mod}}^2}$$

$$B_{opt} = \frac{0.44}{\Delta\tau_{tot}[ns]} \quad [GHz]$$

$$B_{opt} = \sqrt{2}B_{el}$$

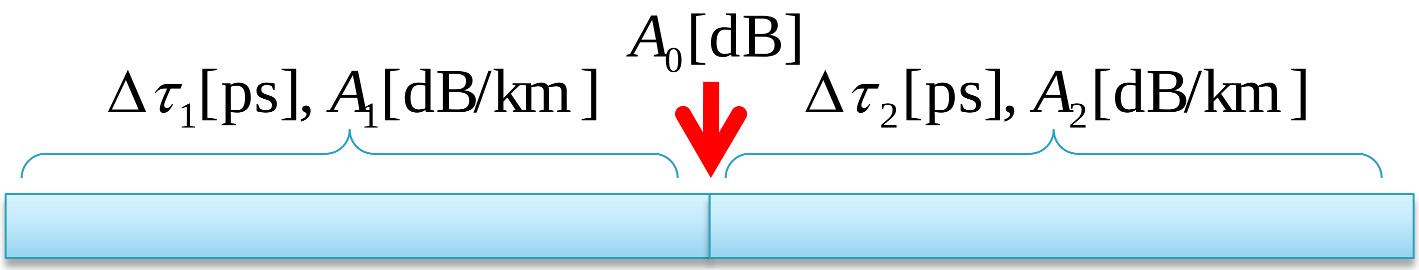
$$V[Gb/s] \cong 2\cdot B_{el}$$

$$\mathrm{B}_{3\mathrm{dB,electric}}(\mathrm{GHz}) = \frac{0.35}{\mathrm{T(ns)}}$$

$$\mathrm{NRZ}_{\mathrm{viteza\ date}}(\mathrm{Gbit/s}) = \frac{1}{\mathrm{T}_{\mathrm{impuls}}(\mathrm{ns})} \le \frac{0.67}{\mathrm{T(ns)}}$$

Sisteme cu mai multe tipuri de fibra

- Fibra tip 1 conectata/sudata cu fibra tip 2
- efecte **succesive** se adună liniar
- la nivelul splice-ului apare o atenuare **localizata**:
    - atenuare pe splice/conector
    - atenuare datorita **NA** diferit (**daca** este cazul)
    - atenuare datorita **Φ** diferit (**daca** este cazul)

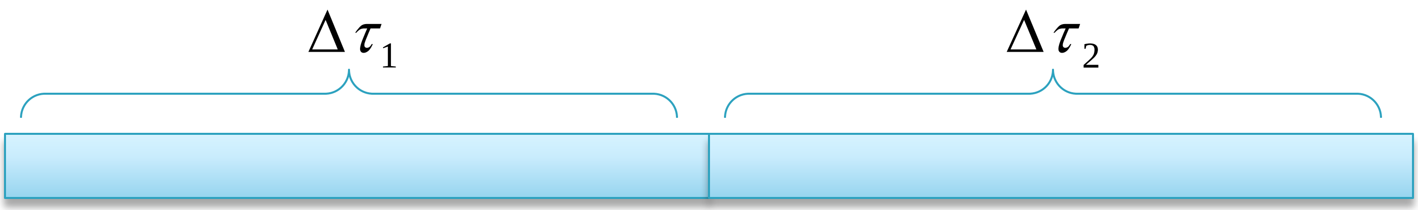


$$A_{tot}[\text{dB}] = A_1[\text{dB/km}]\cdot L_1[\text{km}] + A_2[\text{dB/km}]\cdot L_2[\text{km}] + A_0[\text{dB}]$$

$$\Delta\tau_{tot} = \Delta\tau_1 + \Delta\tau_2$$

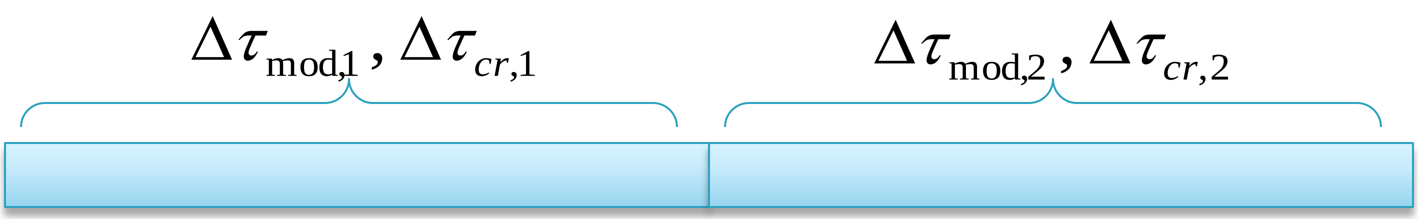
Sisteme cu mai multe tipuri de fibra

- efecte **succesive** se adună liniar



$$\Delta\tau_{tot} = \Delta\tau_1 + \Delta\tau_2$$

- dar pe fiecare fibra exista efecte **simultane** (pentru dispersie) care se adună pătratic



$$\Delta\tau_1 = \sqrt{\Delta\tau_{cr,1}^2 + \Delta\tau_{mod,1}^2}$$

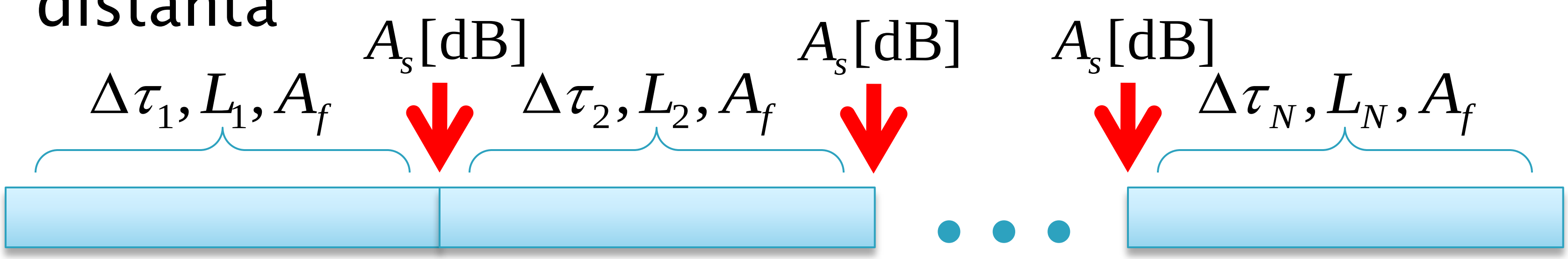
$$\Delta\tau_2 = \sqrt{\Delta\tau_{cr,2}^2 + \Delta\tau_{mod,2}^2}$$

Sisteme cu acelasi tip de fibra

- N tronsoane cu acelasi tip de fibra conectate/sudate
  - atenuare datorita NA **nula** (**acelasi tip**)
  - atenuare datorita Φ **nula** (**acelasi tip**)
  - atenuare pe splice/conector: N–1 conectori
  - lungime totala:

$$L_{tot}[\text{km}] = \sum_{1}^{N} L_i[\text{km}]$$

- efecte **succesive** se adună liniar
- efectele (dispersie si atenuare) proportionale cu distanta



$$\Delta\tau_{tot} = \sum_{i=1}^{N} \Delta\tau(L_i) = \Delta\tau(L_{tot}) = \sqrt{\Delta\tau_{cr}(L_{tot})^2 + \Delta\tau_{\text{mod}}(L_{tot})^2}$$

$$A_{tot}[\text{dB}] = A_f[\text{dB/km}] \cdot L_{tot}[\text{km}] + (N-1) \cdot A_s[\text{dB}]$$

Produs Banda · Distanta

$$\Delta\tau_{\text{mod}} \cong \frac{L \cdot n_2 \cdot \Delta}{2\sqrt{3} \cdot c} \approx \frac{L \cdot NA^2}{4\sqrt{3} \cdot c \cdot n_2}$$

$$\Delta\tau_{tot} = \sqrt{\Delta\tau_{cr}^2 + \Delta\tau_{\text{mod}}^2}$$

$$\Delta\tau_{cr} = D(\lambda) \cdot \Delta\lambda \cdot L$$

$$\Delta\tau_{tot} = const \cdot L$$

$$B_{opt} = \frac{0.44}{\Delta\tau_{tot}[ns]} \quad [GHz]$$

$$B_{opt} = \sqrt{2} B_{el}$$

$$V[Gb/s] \cong 2 \cdot B_{el}$$

$$V[Gb/s] \cong \frac{const}{L}$$

$$V[Gb/s] \cdot L[km] \cong const$$

Lungime maxima

- limitata de atenuare
- lungimea cea mai mare la care pot face transmisia este obtinuta in cazul cel mai defavorabil
  - cele mai mici pierderi permise
  - atenuare distribuita maxima

$$A_{TOT}[\mathrm{dB}] = A_L[\mathrm{dB}] + A_D[\mathrm{dB/km}] \cdot L[\mathrm{km}]$$

$$\mathrm{Atenuare}[\mathrm{dB/km}] = \frac{\mathrm{Pierderi}_D[\mathrm{dB}]}{\mathrm{lungime}[\mathrm{km}]} \qquad L_{max} \Rightarrow \Delta P_{min}, A_{D\max}$$

$$L_{max} = \frac{\Delta P_{min}[\mathrm{dB}]}{A_{D\max}[\mathrm{dB/km}]} = \frac{P_{e\min}[\mathrm{dBm}] - S_{r\max}[\mathrm{dBm}] - A_L[\mathrm{dB}]}{A_{D\max}[\mathrm{dB/km}]}$$

de obicei problema distantei maxime limitate de atenuare se pune pentru fibre monomod

Lungime maxima

- limitata de viteza
- lungimea cea mai mare la care pot face transmisia este obtinuta in cazul cel mai defavorabil
  - dispersie maxima
- doua cazuri in functie de cum e specificata dispersia
  - B×L [MHz·km]
  - S_0[ps/nm^2/km], λ_0[nm]

$$B_{el\min} \cong \frac{V_{\min}[Gb/s]}{2}$$

$\Delta\tau_{tot\max}[\mathrm{ns}]$

$$B_{opt\min} = \sqrt{2}B_{el\min} \qquad \Delta\tau_{tot\max}[\mathrm{ns}] = \frac{0.44}{B_{opt\min}[\mathrm{GHz}]} \qquad L_{\max} = \frac{\Delta\tau_{tot\max}}{D(\lambda)\cdot\Delta\lambda}$$

$B \times L\ [\mathrm{MHz}\cdot\mathrm{km}]$

$$L_{\max}[\mathrm{km}] = \frac{B \times L[\mathrm{MHz}\cdot\mathrm{km}]}{B_{el\min}[\mathrm{MHz}]}$$

Lungime maxima

- limitata de atenuare $L_{\max}^{a}[\mathrm{km}]$
- limitata de viteza $L_{\max}^{v}[\mathrm{km}]$

- lungimea cea mai mare la care pot face transmisia este obtinuta in cazul cel mai defavorabil (din cele doua limitari)

$$L_{\max}[\mathrm{km}] = \min\left(L_{\max}^{a}[\mathrm{km}], L_{\max}^{v}[\mathrm{km}]\right)$$

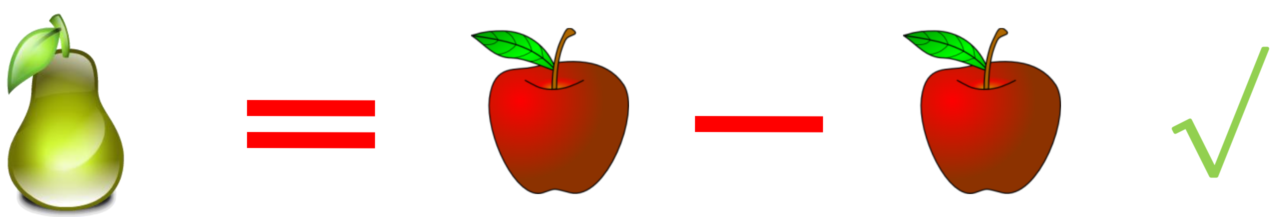
- de obicei
  - monomod: limita impusa de atenuare
    - cu exceptia cazurilor in care nu se functioneaza la λ optim dpdv al dispersiei
  - multimod: limita impusa de viteza

Calculul atenuarii

$$\text{Pierderi} = \frac{P_{out}}{P_{in}}$$

$$\text{Pierderi}[\text{dB}] = [-]10 \cdot \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

$$\text{Pierderi}\,[\text{dB}] = [-]\left(P_{out}\,[\text{dBm}] - P_{in}\,[\text{dBm}]\right)$$



$$\text{Atenuare}[\text{dB/km}] = \frac{\text{Pierderi}[\text{dB}]}{\text{lungime}[\text{km}]}$$

Problema simpla?

- Sursa luminoasa: 7.7 dBm
- Atenuarea fibrei: 1.16 dB/km
- Puterea la iesire: 105 μW

- Lungimea fibrei: ?

Problema simpla?

- Logaritmic
  - $P_{out} = 10 \cdot \log(105\ \mu W / 1\ mW) = -9.8\ dBm$!
  - Atenuarea : $A_f = P_{in}[dBm] - P_{out}[dBm] = 17.5dB$!
  - $L = A_f\ /\ A_{dB/km} = 17.5dB\ /\ 1.16dB/km = 15.08\ km$
- Liniar
  - $P_{in} = 1mW \cdot 10^{7.7/10} = 5.888\ mW$
  - Atenuarea : $A_f = P_{in}\ /\ P_{out} = 5.888\ mW\ /\ 0.105\ mW = 56.0762\ [1]$!
  - Atenuarea pe unitatea de lungime $A_{1/km} = 10^{1.16/10} = 1.3062\ [1]$!
  - $A_f = (A_{1/km})^{L/1km} \rightarrow L = 1km \cdot \log(A_f)/\log(A_{1/km}) = 1.749/0.116\ km = 15.08\ km$

Problema simpla? 2

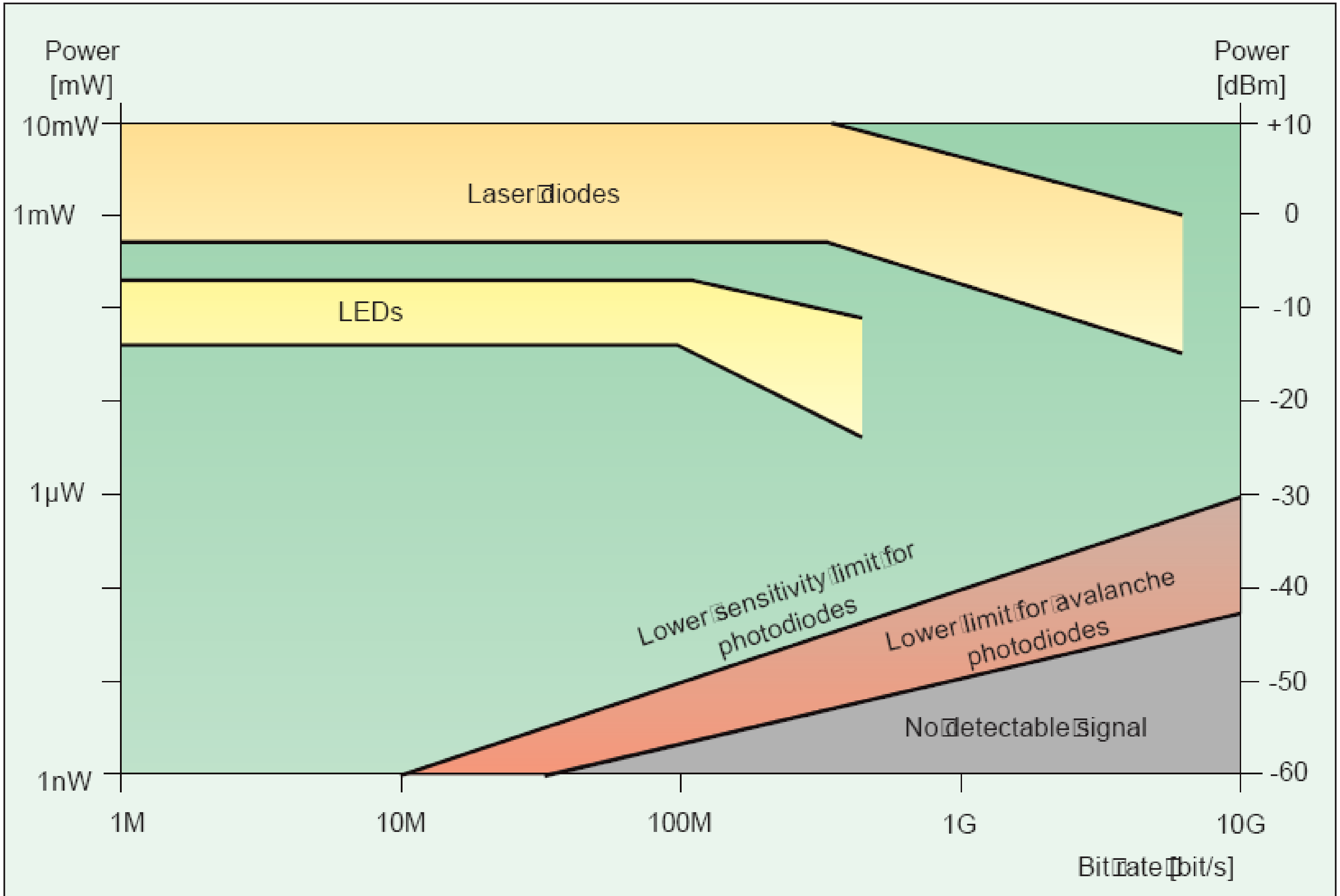
- Sursa luminoasa: 4.9 dBm
- Atenuarea fibrei: 0.32 dB/km
- Lungimea fibrei: 17 km

- Puterea la iesire: ? [μW]

Problema simpla? 2

- Logaritmic
  - Atenuarea : $A_f = A_{dB/km} \cdot L[km] = 5.44$ dB
  - $P_{out}[dBm] = P_{in}[dBm] - A_f\,[dB] = -0.54$ dBm !
  - $P_{out} = 1mW \cdot 10^{-0.54/10} = 0.883$ mW = 883 μW
- Liniar
  - Atenuarea : $A_f\,[dB] = A_{dB/km} \cdot L[km] = 5.44$ dB !
  - Atenuarea : $A_f\,[1] = 10^{Af\,[dB]\,/10} = 3.499\,[1]$!
  - $P_{in} = 1mW \cdot 10^{4.9/10} = 3.09$ mW
  - $P_{out} = P_{in} / A_f = 3.09$ mW / 3.499 = 0.883 mW = 883 μW

Limite putere/bandă a dispozitivelor optoelectronice



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